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SOME SPECIAL PROBLEMS CONNECTED WITH SUPERSONIC TRANSPORT.

Comments on the "Questionnaire" for the IATA Symposium on Supersonic Air Transport in Montreal, April 1961,

by

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ABSTRACT.

This paper deals primarily with two important problems connected with supersonic aviation, namely cosmic radiation and sonic booms. The biological effects of cosmic radiation at the supersonic cruise altitudes are at present, by and large, unknown. Supersonic aviation should not come about until these effects have been fully assessed. The burden of proof in this respect should rest upon those who advocate this form of aviation.

With regard to the sonic boom problem much research remains to be done, and some suggestions are made in this paper. However, present knowledge does indicate that the pressure rises at ground level caused by a supersonic airliner would be unacceptable for operation over both densely and sparsely populated land areas, because of disturbance to people and risk of damage to property and harm to animals. Ships and their passengers and crews would be similarly affected by over-water operations; it therefore seems probable that supersonic flights between the continents would also encounter heavy opposition. However, as it seems commonly held that over-water supersonic aviation will be feasible, a study of the possible scheduling for North Atlantic flights has been made in this paper. It is found that for this scheduling to be convenient and allowing reasonable turn-round times, it will hardly be possible to utilize a supersonic airliner for more than one return flight per 24-hour day.

If, in spite of these difficulties, supersonic aviation comes about, it would hamper the continued development of low-fare subsonic aircraft including V/STOL types. However, even if delayed, improved subsonic aircraft will be introduced, and they will offer increasingly severe competition with supersonic aviation, in particular with regard to low fares.

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1. INTRODUCTION.

There is no doubt that the introduction of supersonic airliners would be a great step forward in air transportation. It is generally believed that in spite of the technical problems involved such aircraft can be developed for introduction before 1970. There are, however, two fundamental problems connected with supersonic operations, which are completely new to civil aviation operations, namely cosmic radiation and sonic booms. These problems will possibly impose so severe limitations as to render civil supersonic aviation, in its presently suggested form, unfeasible. It is, therefore, believed that they should be fully assessed and - if possible - solved before too much effort and money are spent on studies, research and development concerning all the other numerous problems of supersonic transport listed in the IATA Questionnaire and, above all, before steps are taken or premature decisions made which in practice would imply that the introduction of this form of civil aviation cannot be reconsidered. For this reason this paper is almost entirely confined to discussion of cosmic radiation and sonic booms.

Neither of the two problems can be fully assessed nor their implications be appropriately evaluated on the basis of methods and standards commonly used up to now for aviation problems. The main reason for this is that the two phenomena might impose serious hazards and disturbances of a type which to a large extent could affect other people than the passengers or the persons living in the vicinity of airports: cosmic radiation, besides its possible direct physiological effects on the passengers, might have harmful genetic effects and thus cause disease for future children of passengers and crew members, and the sonic boom might imply a more or less serious disturbance, of a new kind, for people living within a wide region under the flight path of supersonic transport aircraft as well as risks of damage to property, such as window breakage.

It is obvious that we have to apply new approaches and standards for the evaluation and judgement of the two phenomena. It is also evident that this must be done by balancing the advantage of gain in transportation time for passengers and freight against the harmful effects due to sonic booms on people on the ground - in particular sleep interference - and damage to property together with the possible risks involved due to radiation.

It should, furthermore, be clear that this balancing cannot be conducted on the basis of merely technical considerations. It is thus imperative that judgements and evaluations are carried out not merely by aviation experts,

but also by medical scientists, by sociologists and by legal experts. As the new problems in question involve aspects of a humanitarian nature they have to be considered also from ethical standpoints with due regard to the rights and integrity of each individual in accordance with basic democratic principles.

For this reason it is of utmost importance that the citizens of countries that would be affected by supersonic aviation be fully informed in advance of all the implications and possible hazards of civil supersonic aviation. Considering the sonic booms, the countries involved would, in fact, be practically all countries of the world if from the very outset extensive geographical limitations for supersonic aviation are not agreed on.

In principle, it is for the governments of the various States to decide on the restrictions required for supersonic aviation to be permitted over their territories and territorial waters. For such decisions it is necessary to look far into the future when assessing the possible implications of sonic booms and radiation and thereby to give full consideration to the following two facts:

(a) Once supersonic aviation has been introduced, it will grow and continue to grow indefinitely - if it is at all an economically sound proposition.

(b) Once introduced, but ultimately found to be a mistake because of protests of the public, it will not be possible for the airlines to turn back to pure subsonic civil aviation without excessive financial losses.

It might be pointed out here that it lies primarily in the interest of those who would have to invest vast sums of money into supersonic aviation - some governments and aircraft manufacturers, a number of airlines - to ensure that all governments of affected countries be given adequate information enabling them to make decisions particularly regarding sonic boom limitations. It is, however, equally important for the money investing agencies to ensure complete assessment, in advance, of the possible radiation hazards and to make the information widely known. If this is not done, people might eventually refrain from supersonic travelling because of fear for radiation, even if, in fact, the danger is negligible.

The comments on the IATA questions regarding cosmic radiation and sonic booms are submitted with the above general philosophy as a background. Then some comments will be made on "Potential Implications", in particular with regard to scheduling of supersonic flights over the North Atlantic and the technical and economical relationship between subsonic and supersonic developments.

Note: As it has not been found practical to group all the views presented in this memorandum within the IATA questions, some of the views are

given under a number of suggested additional questions. Such questions are marked differently from the IATA questions.

2. COSMIC RADIATION

2.1. Properties of the atmosphere.

A-11 If the composition and the physical properties of the air at the supersonic cruise altitudes vary greatly from those at current operating altitudes it may call for special design measures or precautions in relation to flight crew or passengers. What is known of significant differences at these altitudes concerning:

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d) concentration of radioactive particles?

A-12 Cosmic radiation at high altitudes has been mentioned as one of the potentially limiting factors to supersonic operations. Is reliable data available on the intensity and ionization effect of cosmic radiation at supersonic cruise altitudes? Are these effects increased significantly by "cosmic showers" and if so, how frequently do the cosmic showers occur?

A-13 Can any information be provided concerning the so-called "cascade effect" whereby the effects of cosmic radiation tend to be intensified by a metallic cover?

There is an extensive and rapidly growing literature both on the physical radiation phenomena within and outside the atmosphere and regarding the biological (including medical) effects of such radiation. Attachment 1 gives some general information on these two subjects.

The intensity of the primary cosmic radiation, its composition with regard to nuclei of various kinds and its variation with time and geographic position seem to be fairly well known. The main phenomenon that has to be considered with regard to biological effects is probably the ionizing properties of the total radiation (Fig. 1).

Practically all of the primary cosmic ray particles interact with the nuclei of the atmospheric gases and produce so-called secondary particles, i.e. mesons, electrons, neutrons, protons and γ-rays. Coming from the outer atmosphere, between 90,000 - 50,000 ft (27,000 - 15,000 m) the intensity of the total radiation has reached its maximum, whereas the intensity of the primary radiation has decreased considerably. At lower altitudes, continued absorption by the atmosphere diminishes the intensities of both the primary and secondary radiation to comparatively small values.

The intensity of the total radiation shows some regular and rather small variations with time, having mainly diurnal, 27-day and 11-year periods. The dependence on geomagnetic latitude is strong (Fig. 1) and increases with altitude. One has to discriminate between the terms "cosmic showers" and "solar flares". A "cosmic shower" implies a number of particles produced when an energetic particle (a primary cosmic ray particle as well as a secondary particle of sufficient energy) hits a nucleon. The new particles produced in this nuclear interaction are of lower energy than the incoming particle. The "great air showers" are produced at high altitudes, by the more energetic particles of the primary radiation ($> 10^{13}$ eV).

The "solar flares" are visible as extremely bright spots on the sun's surface and are very occasionally associated with a violent, but short-lived, increase in the intensity of cosmic radiation measured at the earth. Solar flares can be grouped into two categories: the very large flares emitting protons in the high-energy range (spectrum ranging from energies around 10^8 up to 10^{10} eV), of which there have been six in the last 18 years, and those discovered during the International Geophysical Year, which have particles of lower energy but are much greater in number.

A "cascade effect" arises when cosmic radiation passes through a shielding mass consisting of a substance of high atomic weight, e.g. a metal; the high-energy components are thereby transformed to a large number of components with lower energy, which, however, is still large enough to influence the living cell. As a matter of fact, the "cascade effect" is often used to greatly amplify the cosmic radiation in order to obtain biological results in comparatively short testing times (Attachment 1).

2.2. Human limitations.

A-22 What radiation levels, cosmic and man-made, can be expected from 50,000 to 100,000 feet? Will they constitute a potential hazard unless special precautions are taken?

A-23 The intensity and ionization effect from cosmic radiation, the variation of these phenomena with altitude, and their biological effects have been the object of intense research. Whereas these physical phenomena seem to be fairly well established for altitudes of interest for present studies of supersonic aviation, i.e. up to about 90,000 feet, the knowledge of the biological effects on man of high ionization and of the primary radiation present above about 60,000 feet, still seems to be rather incomplete, and medical scientists have expressed the opinion that even the fairly weak

ionization intensity at the surface of the earth might be a cause of some of the so-called spontaneous mutations which sporadically appear among man. What, therefore, are the latest findings and opinions regarding the biological effects of ionization of the high intensity present in altitudes around 60,000 feet and of the primary radiation which begins around this height and rapidly increases higher up?

a) What influence has time of exposure on the radiation effects, i.e. in particular would there be a significant difference in the effect on flight crew and passengers who fly frequently in supersonic aircraft compared with those who will rarely travel in this way?

As indicated by the literature and also by Attachment 1, the results of experimental investigations on the biological effects of cosmic radiation on human beings are much more incomplete and inconclusive than is the case with the purely physical aspects.

At present, most medical scientists seem to agree that the radiation intensities within the operational ceilings of present commercial jet aircraft (about 35,000 ft., 11,000 m) are not sufficiently large to be of any biological or medical significance (Ref. 1). If one only considers the magnitude of the ionization dose, it is also maintained that this would probably be fairly harmless even at the altitude of maximum intensity (80,000 ft., 24,000 m). It has, however, been stated (Ref. 1) that above about 60,000 ft (18,000 m) the nature of the radiation begins to change rapidly and that it is therefore important to consider not only the ionization intensity, but also the composition of the various radiation components and their biological effects. In this respect the available information seems at present to be quite inadequate.

Of particular importance are the possible genetic effects of radiation, which are discussed in Attachment 1, and the effects of radiation on areas of the human body in which a vital process is controlled by relatively few cells or on areas where the replacement, or regeneration, potential of the tissue is limited, e.g. the lens of the eye and in the brain (Attachment 1, Ref. 1).

Finally, it is important to observe that there seems, at present, to be no practical way of providing protection from cosmic radiation. Due to the "cascade effect", the metallic elements of the aircraft, for instance the fuselage, will cause a magnification of the radiation intensity by which the radiation might be considerably more harmful than if no metallic covering were present.

2. 3. Suggested additional questions and comments.

Evidently, the biological effects of cosmic radiation at the supersonic cruise altitudes are at present, by and large, unknown. Some experts seem to have a rather pessimistic view on the subject whereas others believe that the hazards involved are perhaps not very dangerous. However, no one seems to have yet firmly stated - still less proved - that harmful biological effects are with certainty non-existent.

This being so, it appears essential that the discussions regarding this subject should at this stage mainly be focussed on the question:

AR-1 Should supersonic aviation be introduced before the biological effects of cosmic radiation on human beings are fully known or at least known to an extent that can be deemed quite satisfactory considering that severe human sufferings due to diseases might be at stake?

AR-2 On whom should the "burden of proof" fall with respect to the existence or non-existence of harmful biological effects?

The answer to question AR-1 is obviously dependent on whether civil supersonic aviation can be deemed necessary for the security or welfare of Mankind or anyone country. If this were the case, it would be justifiable to take certain unknown risks: Military supersonic flying - which, however, has as yet only in exceptional cases been extended to the altitudes contemplated for civil supersonic aviation - is nowadays a necessity for defence purposes and is therefore rightly considered as acceptable as long as no very appreciable injury to crew members has been observed or could be suspected. Recommendations have, however, existed to avoid too long operations at extreme altitudes. Likewise, it has also been considered necessary to undertake explosions of nuclear bombs for military security reasons in spite of certain risks involved for observers and others.

Present and/or foreseen shortages in power supply might also give justification to take small risks for the personnel of atomic power stations, for instance in the form of specifying permissible "safe" radiation limits, in spite of the fact that it is seemingly still an open question whether such a limit exists or whether there is a cumulative harmful effect of all radiation regardless of intensity (Ref. 1).

In this connection a comparison might also be made between supersonic aviation and manned space flight, which by many is considered highly essential for scientific purposes and prestige reasons. Because of the considerable biological radiation hazards connected with manned space flight, it has

been suggested that appreciably higher permissible radiation limits must be applied for such enterprises than the current radioactive industry's radiation protection standards, the imposing of which would prevent realizing "the great gains of manned space conquest" (Ref. 1).

Such an increase of the radiation limits in order to make manned space flight feasible is apparently necessary, but the same reasoning cannot, of course, be applied to supersonic passengers. Whereas the crew members of space craft will be extremely few for a considerable number of decades to come and whereas they in most cases are likely to consent to be shot into space merely as an employment duty for which they receive a salary, the supersonic passengers, who instead pay for their tickets, will, most certainly, not consent to be subjected to any hazardous radiation at all. If anything, they will expect the official requirements with regard to radiation protection to be lower than those valid for employees of radioactive industries.

In the author's opinion, civil supersonic aviation is not a necessity for the security or welfare of Mankind or any one country; it is not, in this respect, by any means comparable to military weapons or atomic power plants. As a matter of fact, the opinion has even been expressed that the profitability of supersonic aviation is so doubtful and at best so marginal, considering potential developments of high-subsonic aircraft, that it would be wise to postpone introduction of supersonic aviation, at least some 20 years, even if the new hazards and disturbances of cosmic radiation and sonic booms had not become topical.

For the said reasons, the author maintains that it is not justifiable to gamble with the health of ticket-paying passengers and their descendants for the sake of the gain in travelling time obtainable with supersonic aviation. The answer to the first question is therefore that supersonic aviation should not be introduced before the biological effects of cosmic radiation are fully assessed.

For this assessment, it is important to observe that the possible harmful biological effects are largely a matter of statistics or probability; the question that has to be answered is whether or not the probability, or risk, of developing cancer, other diseases or defects (such as impaired sight), increases for passengers and crew members of supersonic aircraft and their descendants.

Obviously, a considerable time will be needed before this probability question can be fully assessed. This is, in particular, evident with regard to

genetic effects, even if the research is conducted on animals - and it still remains for the medical scientists to prove that such investigations are applicable also for the more complicated and probably also more sensitive human being. The assessment of directly harmful effects of radiation on passengers and crew members must also take a long time, not least because large "sample sizes" have to be used for the statistical evaluation of the probability aspects.

With regard to question AR-2 it is quite obvious, in the author's opinion, that it would not be right to say that only if we have got proof that the cosmic radiation is dangerous should we refrain from introduction of civil supersonic aviation. The general public, being laymen in these advanced sciences, has a right to demand that the question be approached in the opposite manner: that it must be proven beyond doubt that the danger is non-existent.

Thus the responsibility of the burden of proof with respect to radiation hazard should fall on those who advocate supersonic aviation and on no one else.

It might be emphasized that the adoption of the philosophy defined by the indicated answers to the two suggested questions lies above all in the interest of the airlines as well as in that of the aircraft manufacturers and governments investing money in development and construction of supersonic aircraft. The reason for this is that if the public has not been convinced that no radiation danger is involved in flying with supersonic aircraft - neither for the passengers themselves nor for their future children - there is a clear risk that fear for radiation could seriously limit the supersonic market and thus make this kind of aviation wholly unprofitable.

One thing is quite evident: It would be a serious mistake to bury one's head in the sand and hope that the public might not object to the possible cosmic radiation hazards, if they were kept uninformed by avoiding open discussions of this subject. There is no doubt that people will be getting more and more "radiation-minded" during the decades to come. Unless convinced otherwise, the public will quite naturally have the impression that the very thin atmosphere remaining above an aircraft flying at some 70,000 ft. (where the pressure is merely about 6% of the pressure at the ground level), cannot possibly offer the same protection against cosmic radiation as is provided close to the earth surface.

3. SONIC BOOM

3.1. Tolerable pressure rise.

The IATA question reads:

A-31 Aircraft travelling at supersonic speed produce shock waves which give a sharp pressure rise or "sonic boom" when they make contact with the ground. A pressure rise on the ground of 1 lb/sq.ft (5 kg/sq. metre), equivalent to a sound pressure level of 128 dbs, has been mentioned as the maximum tolerable figure for noise from this source. Is this considered to be a realistic target?

The opinion of boom pressure rises less than 1 lb/sq.ft as being tolerable, seems to stem from the NASA tests at the Wallops Station reported in Ref. 2 and 3. In these reports, the reactions of the observers of fly-past tests with supersonic fighter aircraft are recorded. They are reproduced in Fig. 2 together with observed damage of property in connection with these and other tests. A decibel scale is also inserted in Fig. 2, but it should be observed that a certain decibel value for a sonic boom is less disturbing to the human ear than the same value for a normal noise with fairly long duration, the reason being the extreme shortness of the boom, merely a fraction of a second. - It is likely that the tests referred to were made at day-time and, furthermore, that the observers were accustomed to the rather severe noise produced by jet aircraft, in particular during take-offs.

Because of the fact that sonic bang disturbances will sweep the ground surface along the entire supersonic flight path, this new type of noise will affect not only inhabitants of cities within the very wide "boom carpet" (Fig. 3) but also numerous people who have not previously been appreciably disturbed by aircraft noise, not least people living in the open country and in small communities, as well as passengers and crews of ships.

It is obviously necessary to consider the sonic boom disturbance very carefully and without prejudices from the way in which airport noise problems have been treated up to now. A number of additional questions are suggested for the purpose of establishing one or more figures for maximum tolerable bang intensity:

AS-1 Should the limit for acceptable sonic boom intensity be judged on about the same basis regarding public disturbance as has been applied for airport noise or should more stringent requirements be demanded?

AS-2 Should disturbance of sleep be considered as a major criterion on the tolerable boom intensity, and if so, should the permissible

intensity be based on what it takes to awake a light sleeper or an average sleeper?

AS-3 What are the boom intensities corresponding to awakening of light sleepers during various circumstances with regard to background noise, etc. ?

AS-4 If disturbance of sleep should be a decisive criterion for tolerable boom intensity, should that mean that consideration should only be given to those who sleep in night-time, say between 22.00 - 07.00 hours, or should the determination of the acceptable limit or limits be based on the fact that many people are dependent on undisturbed sleep at day-time, for instance because of work at night?

AS-5 What is the acceptable boom intensity with regard to hospitals, convalescent homes, resort places etc. ?

AS-6 It has been suggested that supersonic flying might have to be prohibited over densely inhabited areas but could be permitted over sparsely populated districts. This suggestion is probably based on a philosophy that geographical limitations of sonic bang disturbance could rightly be based on the number of people that will be disturbed, or on the number of actual complaints. Is this philosophy justifiable from a humanitarian standpoint? If not, what basic philosophy should be applied?

AS-7 What are the acceptable boom intensities with regard to disturbance of animals, considering not only commercial aspects regarding, for instance, animals being bred at fur farms, but also aspects of prevention of cruelty to domestic and wild animals?

AS-8 What are the tolerable boom intensities with regard to passengers and crew members of ships at night- and day-time, considering in particular that some crew members normally have to sleep in day-time because of shift-work?

AS-9 Having established tolerable boom intensity limits for the various considerations specified above, primarily for one or a few bangs e.g. every day or night, what reduction of these limits should be made in order to account for the increased, and to some extent cumulative, disturbance effect due to large numbers of sonic booms every night and day?

AS-10 What legal problems would be involved with regard to sonic bang disturbances and damage to property?

It should be observed that most of these questions about the tolerable pressure rise are interrelated with extension of the disturbed areas. The figures 2-5 give some information for typical examples, about the maximum bang intensity straight below the flight path, and the lateral distribution of the intensity within the limits of the bang carpet.

With regard to the first question, AS-1, it might at first sight appear

that if the en-route sonic boom noise is not any worse than the present "tolerable airport noise", then it would - or must - be accepted by the public. The reason for such an attitude could be that as people living in the vicinity of airports have - more or less reluctantly - accepted a certain amount of noise disturbances, one would think that it could be rightly demanded that people living away from airports or cities should also put up with noise disturbances of about the same severity.

With some afterthought it is, however, quite obvious that the problem of tolerable sonic-boom noise is much more complicated than indicated by such an approach. In the first place, it must be observed that the acceptance of even rather high airport noise levels must be understood as a matter of necessity. All means of transportation - trains, trucks, cars, motorcycles, etc. - are noisy and, although there is a growing opposition against the present magnitude of such disturbances, it is appreciated by the public that fairly high overall noise levels - and still higher peak levels - just have to be accepted in large cities and close to highways and railroads, at least as long as no radical improvements with regard to noise suppression at the source have been made. The same applies to airport noise in spite of the fact that this has usually a wider extension than the noise from, for instance, railroads and highways.

It can in other words be stated that the present public acceptance of rather severe noise disturbances in the vicinity of airports is to a large extent based on - a conscious or unconscious - appreciation of the fact that civil commercial aviation just could not exist without being allowed to create considerable annoyance in connection with leaving and returning to the airport.

It must also be borne in mind that inhabitants of cities who feel that the airport noise, in particular at night-time, is too disturbing, are to a large extent living - or able to move - rather far away from the city airport and thus enjoy quietness at least at night, even for the case where they have to work close to or at the airport.

This last observation leads, in fact, to the probably most important fundamental difference between normal airport noise and sonic bangs. Even if the supersonic routes are planned so that the sonic-boom noise carpet avoids large cities, they will inevitably sweep considerable numbers of middle-sized and small communities as well as single houses, cottages, people travelling, etc., in the open country. Not only is the total width of

the bang carpet rather big - some 80 - 100 miles (120 - 160 km) - but it must also be considered that the pilot for many reasons might have to deviate appreciably from a basic route, such as a straight-line connecting two points. Evidently there will be imminent risks of sonic bangs within a much wider area than that of the bang carpet.

This being so, supersonic aviation over the continents - with no other restrictions than avoidance of large cities - would affect quite considerable portions of the various countries. It must also be taken into account that supersonic aviation, if at all an economically sound proposition, will continue to grow indefinitely - as pointed out in the introduction - and that consequently new routes will be introduced in the future. These two observations imply that a large percentage, often the majority of the people in such countries that permit supersonic aviation, would be affected by sonic bangs in one way or another. Large portions of the countries will therefore be disturbed in the opening phase of the supersonic era and other portions would run a risk to be disturbed as supersonic aviation develops.

It thus follows that many people, from tens of thousands to many millions depending on the size of the country, would suffer from this new kind of disturbance and would to a large extent have to consider moving to districts unaffected by sonic bang carpets, which often necessitates change of employment and homes. In selecting sites for new employment and homes, it would be necessary to look into the future and try to obtain information from airlines regarding portions of the country that one can fairly safely count upon being for ever at safe distance from any conceivable supersonic routes.

Another significant difference between city airport noise and sonic bangs is that, whereas normal airport noise is characterized by fairly long duration peaks during take-offs, climbs and approaches and a rather high constant background noise, at least in day-time, the sonic bangs are quite sharp, sudden and thus unexpected. For pressure rises above a certain level - about 1.0 lb/sq. ft or possibly less - the bangs are for many people quite startling (Ref. 3) and even frightening. It seems therefore probable that the average citizen will never be able to get accustomed to sonic bangs to the same extent as is often the case with normal airport noise and other large-city noise disturbances.

In view of all the above circumstances it seems evident that the limit for acceptable sonic boom intensity cannot be judged on the experience from airport noise and, furthermore, that considerably more stringent require-

ments should be demanded with regard to the sonic boom disturbances than for airport noise, AS-1.

To the specific IATA question (A-31), whether 1 lb/sq.ft. can be regarded as a realistic target, it follows from Ref. 2 and 3 (Fig. 2) that for boom intensities exceeding this value "the observers were startled even though forewarned of the impending boom" and that they considered such booms objectionable. Judged on this information alone, it seems obvious that a limit of 1 lb/sq.ft. would be too high with regard to disturbance of people of any age and state of health living at any place all over a country.

With respect to physical damage, a pressure rise of 1 lb/sq.ft. seems to be about the limit at which some window damage begins to occur and fairly rapidly increases with more intense pressures.

Another important factor is the fact that the boom intensities might be considerably stronger at local points if the supersonic flight is not quite steady and straight (Ref. 4). Thus it is possible for the boom to be magnified in accelerated flight as well as due to focussing effect connected with phugoid motion of the aircraft. The possible magnitude of such magnifications ought to be studied by extensive tests, but existing theories seem to indicate that local booms might be 2 - 3 times larger than those calculated by theory and observed at steady, straight-course flight tests. It should, furthermore be observed, that when the bang carpets of two supersonic aircraft intersect or interfere with each other, for instance when one aircraft overtakes another on the same route, an addition of the two pressure rises will occur locally.

If the acceptable limit were set to 1 lb/sq.ft., this might thus result in local pressure rises of the order of 2.0 to 3.0 lb/sq.ft. and then damage to property would, of course, be rather severe. In this connection it might be mentioned that on some occasions sonic booms have actually caused fires because of electric shorting due to the vibrations imposed on buildings.

It is obviously necessary to agree on a criterion for the acceptable boom intensity either with regard to disturbance of people or damage to property. Studies conducted in Sweden indicate that if the permissible boom intensity is set so as to just avoid all window cracking, there would still be more or less severe public annoyance. It therefore seems obvious that the reaction of people should be the dominating factor to consider and this leads to the suggested question AS-2, regarding sleep disturbance.

As it cannot be questioned that sleep is of fundamental importance for

health, and for recovering from illness, there seems to be little doubt that sleep interference should be one of the basic criteria. In the author's opinion, one should then in the first place consider the boom intensity required to awake a light sleeper rather than an average sleeper. The reason for this, is simply that the light sleepers should, in principle, have the same right to enjoy undisturbed sleep as other people. It might also be pointed out that even a person who sleeps well and deeply often will be unconsciously disturbed by one or repeated sharp booms by night even if he does not actually wake up.

On the question AS-3, what boom intensities are required to awake light sleepers, extensive tests are undoubtedly needed. Tentatively, the author would imagine that the intensity should not exceed 0.1 - 0.2 lb/sq.ft. (0.5 - 1.0 kg/m^2) if there is a low level background noise and 0.2 - 0.4 (1.0 - 2.0) if the background noise is of a normal day-time level, say that prevailing in a suburb or a small community distant from airports.

The reason why fairly low level background noise should be considered is that it is particularly important for people with sleeping difficulties to enjoy a maximum of quietness, because such people are often light sleepers and compelled for health reasons to live in quiet parts of communities or in the countryside.

Regarding the time of the day that should be considered with respect to sleep interference (AS-4), it might at first sight seem sufficient to take into account merely the night period, say from 22.00 to 07.00 hours. This cannot, however, be right because there are almost everywhere in the communities or in the open country quite a few people who are dependent on undisturbed sleep at day-time. Shift workers have anyhow often difficulties to get a sufficient amount of sleep and there are everywhere in the country many people, in particular elderly and sick people, for whom undisturbed sleep during part of the day-time is of vital importance.

This leads to the question (AS-5) about acceptable bang intensity with regard to hospitals. Obviously the demand for hospitals, in particular mental hospitals, with respect to quietness is of greatest importance. Sharp, unexpected sonic bang claps might well be detrimental to the patients and could severely influence surgical operations. It is therefore highly important to determine by special investigations the acceptable boom intensity for hospitals. This will probably be still lower than the acceptable limit with regard to light sleepers. If, therefore, the permissible limit is governed merely by the latter consideration, then the supersonic flight routes have to be planned

so as to ensure that the wide bang carpets fall with a safe margin outside all hospital grounds. It must be observed, however, that such a policy would still be disadvantageous with regard to continued erection of new hospitals during the decades to come for the obvious reason that it would limit a free choice of well located sites for such constructions.

In this connection, it should also be observed that in most countries there are numerous resort places and convalescent homes and other locations especially selected by retired people, for which quietness might be of nearly equal importance as for hospitals. It should also be borne in mind that vacations in quietness, not least for over-worked or nervous people, are of great importance for prevention of illness.

For the reasons indicated, it seems worthwhile considering acceptable bang intensity with regard to hospitals as a basis for sonic bang requirements.

The above comments are believed to indicate the answer to the important question AS-6. This question could be expressed more exactly as follows: If a certain supersonic operation is considered intolerable if conducted over densely populated areas, could it then be deemed acceptable if the flying routes are allowed to pass over sparsely populated districts, because fewer people would then be disturbed? The author maintains that it would not conform with humanitarian democratic principles to legalize harmful effects on people merely because they are relatively few in number. In civilized countries people who suffer from diseases, including uncommon ones, are well taken care of, and no one would say that their cases are unimportant and could be disregarded because they are few in number.

We have already come to a point of social development where prevention of sickness is considered as about equally important as the recovery of sick people and this tendency will undoubtedly continue to grow. Would it then not be quite illogical to completely disregard the fairly few, but yet perhaps more than hundreds of thousands of people, who might be subjected to sufferings because of sonic bangs? Such a policy will result in impaired health, and even sickness necessitating hospital care, for a considerable portion of the people so affected.

With regard to airport noise, the tolerable level of disturbance has to some extent often been assessed by the number of complaints. This seems to be a rather dubious method but might still have some justification as a matter of necessity. It is, however, maintained that the "number-of-com-

plaints" criterion should by no means be the basis for the acceptability of sonic bang disturbances all over the continents. The only defendable basic philosophy from a humanitarian standpoint is that each single individual should have the right to quietness and solitude if he deems this essential.

Regarding the question of disturbance of animals by sonic bangs (AS-7), which ought to be thoroughly studied by experts, it is well known that fur animals are particularly sensitive to noise and that therefore fur breeders often have suffered considerable losses because of subsonic aircraft flying over fur farms at low altitudes. Evidently, the aspect of prevention of cruelty to domestic and wild animals has also to be considered for the sonic bang type of noise. It could be argued that animals would get used to the sonic bangs in view of the fact that they do endure thunder. There is, however, an important difference between sonic bangs and normal thunder in that the latter is usually of a gradually increasing character, whereas the sonic bangs, as said, are quite sudden and without forewarning. It should also be observed that extensive supersonic aviation would lead to numerous bangs each day, whereas thunderstorms are usually limited to a few occasions each year.

The question of disturbance of animals is particularly important with respect to geographic restrictions of supersonic flying because both reared and wild animals often exist in large numbers in districts which are sparsely populated.

If the general philosophy indicated by the above comments is accepted, that will probably lead to prohibition by the governments of various countries of supersonic flying over practically all parts of the continents, because it would be impossible or at least difficult to lay out routes between any two large cities in such a way that the supersonic parts of the routes pass entirely above uninhabited areas with no, or merely a few, fur farms or the like. This conclusion is, of course, also based on the presumption that it would be unfeasible to ascertain a sufficiently low bang disturbance by reducing the size of the aircraft (see Fig. 5).

It then remains to discuss the acceptable sonic boom intensities with regard to supersonic flying over the oceans between the continents (AS-8). At first sight, it would seem that one could allow appreciably higher bang intensities over sea than over land, because (a) the "ship density" is usually fairly small, (b) most ships have rather small and thick windows, and (c) many ships are noisy anyhow.

For several reasons the author maintains, however, that one should not

treat the sonic bang problem for over-sea flying too lightly. In the first place, we must again respect the principle that one should not unduly disturb people just because they are few in number. Many ships, in particular the big ones, have cabins which are very quiet and do not differ much in this respect from ordinary houses, and there are also ships with fairly large glass windows. Sonic bang intensities of the order of 0.5 lb/sq.ft. would probably awake some passengers and crew members at night, and with pressure rises from 1.0 or 1.5 lb/sq.ft. and upwards most people on board will be awakened and, besides, an increasing amount of window shattering will occur. At day-time, passengers would be frightened by sudden sonic-bang claps, in particular when they are enjoying quietness on deck, a factor which is not unimportant for tourist liners.

Equally or more important are the disturbance effects on the crew members. Shift work is a normal procedure on boats, and it is therefore essential that the possibility of the crew members to sleep both at night and day is not appreciably impaired by supersonic flying.

The conclusions are that there is not a very big difference between the acceptable bang intensities for over-water supersonic flying, compared with the levels that can be deemed acceptable on land. Neither should there be a big difference between the acceptable intensities over sea at day- and night-time.

As the oceans outside the borders of territorial waters do not come under the jurisdiction of any country, it seems natural and essential that the various shipping agencies and yachting and fishermen associations are consulted with regard to sonic-bang disturbances and that the tests to be made for assessing them are conducted in close cooperation with such agencies.

With regard to question AS-9 on the relation between acceptable sonic-bang intensity and the frequency of bang occurrences, it should be observed that the experience up to now of military supersonic flying is quite inadequate for establishing this relationship. Military supersonic operations, which have largely been confined to fairly small aircraft, are usually of a rather irregular or sporadic type. The operations do not usually affect one and the same area each day or even each week.

Civil aviation with supersonic airliners would be quite different in this respect. Upon introduction - assuming again that no severe limitations are imposed - the operations will very soon for most routes comprise at least

a couple of flights per day between many cities, and as the supersonic activity grows, as one has to presume, there would then often be dozens of flights on one and the same route during the 24-hour day. This means, of course, that the judgement of the acceptable sonic-boom pressure rise should be based on the assumption of a future large multitude of supersonic flights each day and night. In this connection it should be observed that the more supersonic aviation is restricted to a limited number of routes over sparsely inhabited areas, or over sea, the more frequent flights on the routes will be made.

Thus, instead of sporadic complaints following the irregular military supersonic operations, we would be faced with repeated disturbances over the same vast areas every day and night. This will undoubtedly lead to complaints on quite another scale than has hitherto been experienced. - It is, indeed, hardly possible to exaggerate the sufferings that would be inflicted on a person who all the year round is not merely awakened once or twice every night but might be so frequently mentally disturbed by several bangs at night-time that he often hardly gets any sleep at all. The same reasoning applies to those who have to sleep in day-time.

The legal problems involved due to sonic bangs (AS-10) will naturally be strongly dependent on the bang intensities and the frequency of the supersonic flights. If, for instance, the core of the en-route bang carpets is of the order of 1.5 lb/sq.ft. - which might imply about 2 lbs/sq.ft. during the supersonic climb - and if no particularly severe geographical limitations are imposed, millions, or even tens of millions of people would be subjected to quite intolerable disturbances every day and night. Furthermore, tremendous numbers of windows would be shattered not only of buildings but also of green-houses. There would probably also be a considerable amount of still more serious damage to property, even including risks to individuals, for instance because of fires due to shorting of electric circuits, shattered glass roofs, etc. The harmful effects on people and property would be particularly severe when magnification of the bang pressure rise occurs because of unsteady flight or interference between two bang carpets as pointed out above.

With regard to the nature and frequency of the legal issues for the case of extensive bang carpet cores of 1.5 to 2.0 lb/sq.ft., "the suffering of innocent, ear-shattered citizens" would probably be of the greatest importance, as pointed out in Ref. 5, but also damage-to-property cases and losses to fur-farms will certainly be quite frequent, if rather severe bang restrictions

are not imposed. Many other types of legal cases are also conceivable, such as losses to hotels, convalescent homes and the like because of reduced number of guests. Furthermore, one cannot overlook the possibility of people with weak hearts being killed by sudden sharp sonic bangs.

If, on the other hand, the size of the supersonic aircraft, the cruise altitude and the climb and descent procedures are such that the core of the bang carpet will not normally exceed, say, 0.5 lb/sq.ft., the number of legal cases would, of course, be greatly reduced. They would, however, not be eliminated at all because of the cases of local magnifications and also because of the fact that, even at such an intensity, numerous people would be disturbed in their sleep and would most likely bring sues against the offenders.

Tentative conclusions: The purpose of the above comments on the suggested ten additional questions is mainly to draw attention to the many considerations that have to be taken into account for answering the IATA question on a realistic figure for the maximum tolerable sonic-bang intensity. As indicated and will be discussed further on, very extensive tests are required in order to establish a basis for national and international requirements or standards regarding sonic bang creation.

A general principle or policy for the target standard in this respect has already been indicated by ICAO. In the ICAO Doc 8087-C/925, Aug. 1960, "The Technical, Economic and Social Consequences of the Introduction into Commercial Service of Supersonic Aircraft", (Ref. 6) the following statements are made:

> § 280 (p. 88) "Judging from the replies of States to the ICAO questionnaire, it seems clear that in the economic and social fields any supersonic aircraft will have to satisfy the following conditions:
>
> -------
>
> iv) it must not cause serious trouble to the public living in the vicinity of air routes owing to the impact of the sonic boom"
>
> -------

and

> § 283 ------- "if supersonic airliners not satisfying these conditions are placed on the market ------- they would meet with such great resistance from government and airport authorities that it seems unlikely that they could be operated at all between ICAO Contracting States."

It is, of course, difficult to determine what should be meant by "serious

trouble to the public". Most light sleepers, as well as sick and elderly people, would certainly maintain that wakening up by sudden bangs night after night should rightly be classified as serious trouble. People who have to sleep in day-time would no doubt take a similar view.

In this connection, the author would like to express the general opinion that one should not merely consider actual cases of broken sleep but also pay serious attention to recent findings on the detrimental nervous effects that noise can cause even for cases where a person is not actually conscious about the disturbance. Dr. Albert Besson, member of "L'Académie de Médicine de Paris", President of the "Ligue française contre le bruit", states (Ref. 7):

> "Noise has become a veritable social danger. Not only does it influence the auditory organ, it affects the whole human organism, in particular the nervous system."

Finally, with a view to stimulate discussion on the subject of establishing an acceptable maximum bang intensity figure, the author wishes to submit a tentative estimation in spite of the present lack in test results and experience:

In consideration of the above quotations and the comments to the suggested additional questions, it is believed that the permissible bang intensity limit for steady supersonic climb, en-route and descent flight over such land districts which are not practically uninhabited should fall somewhere between 0.1 and 0.3 lb/sq.ft. on the basis of sleep interference (see above). Over sea, wherever there is any risk of the bang carpets covering ships, the limit could possibly be raised to somewhere between 0.3 and 0.6 lb/sq. ft.

Whatever maximum bang intensity limits are finally required, it should be observed that supersonic aircraft can probably not be designed right up to the limits. An adequate "bang safety factor" must be applied so as to account for an acceptable frequency of increased bang intensities due to deviations from steady unaccelerated straight flight (see Section 3.2). Also, for establishing this safety factor extensive tests are needed. In this connection the following quotation from Ref. 4 might be of interest:

> "Any radical departures from steady-level flight conditions during any of the supersonic portions of the flight should also be avoided since these may lead to intense sonic booms over localized areas on the ground."

3.2. The variation of sonic boom with different parameters.

The IATA questions on this subject are:

A-32 A number of factors will affect the magnitude of the pressure rise in the shock wave and thereby the magnitude of the sonic boom experienced on the ground. What effect will each of the following factors have on the strength of the shock wave at the aircraft:

a) aircraft speed?

b) aircraft acceleration?

c) ambient pressure at flight altitude?

d) ambient temperature at flight altitude?

e) aircraft body shape (volume, fineness ratio, aerodynamic cleanness, etc.)?

f) aircraft weight?

g) Lift/Drag ratio and aircraft "lift effect"? (In view of the controversial nature of the lift effect theory, how soon can definite proof or contradiction of the theory be expected?)

A-33 What effect will the following factors have on transmission of the shock wave from the aircraft to the ground, and therefore on its strength at the ground:

a) aircraft altitude above ground?

b) aircraft attitude?

c) pressure gradient?

d) temperature gradient?

e) wind gradient?

f) cloud cover, precipitation, humidity, etc.?

A-34 What effect will the following factors have on the shock wave experienced by an observer on the ground due to an aircraft in supersonic flight:

a) terrain and disposition of buildings on the ground (i.e. will there be a "focussing" effect)?

b) wind?

c) lateral displacement of observer from aircraft flight path?

d) the presence of more than one aircraft in the immediate vicinity flying supersonically?

With regard to the first question, it might be pointed out that "at the aircraft" the shock wave pattern is more complicated than beyond a certain distance from the aircraft where the typical N-shaped shock wave is developed. Furthermore, as the shock wave properties, e.g. the bang pressure

rise, at the ground are of predominant interest, the subquestions of A-32 are preferably transferred to A-33.

The existing theory for the sonic bang pressure rise is briefly surveyed and exemplified for the ICAO standard atmosphere in Attachment 2*) (Ref. 8), indicating the variation of the pressure rise at sea level with various parameters. The figures 2-5 give some further examples of important relationships.

Fig. 2 illustrates the relationship, for a supersonic transport of about 400,000 lbs. (180,000 kg) gross weight, between pressure rise, Mach number and altitude for the ranges of altitude that have been suggested for supersonic climb (exceeding about 35,000 ft.) as well as for cruise (60,000 to 80,000 ft.). The figure shows that the pressure rise increases very rapidly as the Mach number exceeds 1.0. This means that the bang intensity on the ground will be greater during climb than during cruise, if the supersonic part of the climb is not postponed to an altitude near the cruise altitude. During descent a similar increase of the bang will occur but that will be less serious because the aircraft is then normally much lighter due to the fuel consumption en-route. In the calculations no correction has been made for the climb angle, because it is believed that the relief due to this factor will not be very great as the climb angle for this type of aircraft will be small and the relieving effect might be counteracted by the increased lift coefficient at climb.

The extension of the bang carpet, both the climb and cruise portions, is illustrated in Fig. 3 for the same example as that of Fig. 2. As is to be seen, the climb portion for this example has a length of about 200 miles and a width of about 60 miles within which the intensity exceeds 0.5 lb/sq.ft. The climb bang intensity reaches a maximum of 2 lb/sq.ft. and the extension of the core of the carpet that has pressure rises exceeding 1.5 lb/sq.ft. is about 20 miles.

It follows from figures 2 and 3 that, if for reasons of efficiency a considerable part of the climb must be made supersonically, the pressure rise in the climb-bang-carpet will be the determining factor - in the first place for the highest possible weight of the aircraft - for compliance with a maximum permitted bang intensity. This conclusion is, of course, only valid provided that supersonic climb cannot be conducted so that the climb-bang-

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*) Not attached to all copies of this Memo.

carpet can be guaranteed to completely fall on an uninhabited area or over a sea area where there are no (or at the most very few) ships. This condition will, however, in practice be rather difficult to comply with because of the vast extension of the climb-bang-carpet and the fact that the risk zone for climb pressure rises is still much bigger, for the event of strong wind and because of possible deviations from the planned average courses.

In Fig. 3, the altitude scale in the upper part of the figure is different from the scale for the lateral extension of the bang carpet in the lower part of the figure. This gives a wrong impression of the width of the bang carpet. In order to illustrate the actual conditions, the same altitude and lateral scales are adopted in Fig. 4 for a 400,000 lb SST flying at 70,000 ft. (21,000 m) and producing a maximum pressure rise of 1,5 lb/sq.ft. In the figure, the lateral pressure rise distribution is also indicated: the total carpet width is about 93 miles (150 km), the width of the core with pressures exceeding 0.5 lb/sq.ft. is about 55 miles (90 km) and the width of the core exceeding 1.0 lb/sq.ft. is 35 miles (55 km).

In Fig. 4, a comparison is also made with the width and pressure distribution of a bang-carpet produced by a Mach 2 military aircraft flying at 20,000 ft. (6,000 m) and having such a weight (25,000 lbs., 11,500 kg) that the maximum bang intensity is the same (1.5 lb/sq.ft.) as that for the SST flying at 70,000 ft. It is important to observe that for this example, the total carpet width is 2,8 times larger for the SST than for the military aircraft, the ratio being 1.8 for the core exceeding 0.5 lb/sq.ft. and 2.4 for the core exceeding 1.0 lb/sq.ft. As this military aircraft is fairly representative of many present supersonic fighters, several countries have already had some experience with sonic bangs up to and probably above 1.5 lb/sq.ft.

In Sweden, contemplated new regulations about supersonic flight altitudes are such that only about half of the value 1.5 will be reached in daily routine operation and that bangs of the order of 1.5 lb/sq.ft. will be reached merely in connection with special fairly infrequent exercises which if possible, should be planned so as to locate the bangs over sea. For England, the information has been received that military supersonic operation over land is prohibited, but this has no doubt come about after some considerable experience and complaints regarding sonic bangs.

The most important point illustrated by Fig. 4 is that, whatever experience various countries have had up to now with comparatively small

military supersonic aircraft producing sonic bangs of about 1.5 lb/sq.ft., it should be observed that not only will the total width of the bang carpet for a commercial supersonic airliner be much bigger than for the military aircraft, but also will the core of the carpet, comprising really severe bang pressures, be much wider. To this comes, as pointed out above, the fact that supersonic airliners will normally fly the same route many times a day, whereas military aircraft usually do not cause a bang on the same area very often.

Fig. 5, finally, indicates the relationship for Mach = 3 between pressure rise and aircraft weight for various suggested flight altitudes and lateral displacements (b) from the flight path. The figure shows that even a moderate limitation of the maximum permitted pressure rise to say 0.5 lb/sq.ft. would limit the aircraft gross weight to something around 25,000 lbs. (11,500 kg).

With regard to the validity and accuracy of the applied theory,. some test results (Ref. 3, 9) indicate a fairly good confirmation of the theory, but the importance of the subject makes extended testing highly desirable. This applies particularly to flight altitudes above some 40,000 ft., where the lift component of the shock wave is predominant. It is, however, rather unprobable that the theory for the steady flight case would have to be substantially modified.

An important matter is the value of the ground-reflection factor that should be applied. Some NASA tests have indicated a value of 1.8 (Ref. 3) and that has been used for the figures 2-5. If another value is believed to be more representative for any actual case, a correction can easily be made because the pressure rise is directly proportional to the ground-reflection factor.*)

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*) It might be observed that a reflection factor $>$ 1.0 corresponds to the condition at or close to a reflecting surface such as a normal ground surface or a window. A person standing up will perhaps not normally feel a pressure rise much greater than that corresponding to a reflection factor of 1.0. The reactions of the observers of the tests of Ref. 3 were, however, recorded with reference to the measured pressure rise close to the ground, thus with a reflection factor of about 1.8. - If one speaks in terms of the unreflected wave pressure rise, both the curves of Fig. 2-5 and the values for people's reactions, certain damage to property and suggested acceptable limits should be divided by 1.8. - It might be better to refer all observations and physiological reactions to the pressure rise in the unreflected wave (reflection factor 1.0).

It should be pointed out that, apart from the value of the ground-reflection factor, one cannot expect the theory to yield values with an accuracy better than say $\pm$ 10 to 15%. It should then be observed that even with bang intensities some 25% lower than those given by the theory and illustrated by the figures, the bangs would still be so severe as to make the conclusions of this Memorandum, by and large, valid. Only if the present theory exaggerates the pressure rise by a factor of about 5, would the disturbances possibly comply with the general demands that are likely to be set by the public and by governments, as discussed in the previous section.

Pending further tests and following the present theory, it remains to discuss whether it is possible to reduce the bang intensity by changing the aircraft configuration. As indicated in Attachment 2 and other references, the only factor, a change of which could appreciably decrease the bang, is the slenderness ratio. It can easily be shown, however, that the slenderness ratio - e.g. defined as the ratio between the length of the aircraft and the square root of the maximum cross-sectional area - that would have to be adopted to reduce the pressure rise merely by a factor of 2, would be so big as to render the aircraft quite unpractical.

A few comments will now be made on those of the above listed IATA questions not dealt with in the foregoing. Deviations in temperature and pressure from an assumed standard atmosphere do not seem to have great influence on the boom intensity judging from present theory. However, some occurrences of considerable physical damage have been reported in many countries indicating appreciably higher boom pressure rises than would be predicted by theory. It has been suggested that factors such as temperature inversion and unsteady tail or head wind might have been responsible.

The aircraft attitude has a certain influence on the bang intensity in that this is reduced in climb and increased in descent. With the fairly moderate climb and descent angles that will have to be applied for supersonic airliners, the influence of aircraft attitude is, however, believed to be rather small (see also Fig. 8 of Attachment 2, Ref. 8). The influence of cross-wind is also fairly small. If, for instance, the wind is assumed to be 100 ft/sec. (30 m/s) all the way from the ground up to the flight altitude, that would merely displace the boom carpet about 8 miles (14 km), (Fig. 9 of Attachment 2). Cloud-cover, precipitation and humidity are not believed to have significant influence.

The effect of terrain and disposition of buildings on the ground might be

important as it may cause echo in the same way as thunder. Of importance is also the interference on the ground between the bang carpets of two supersonic aircraft. As has already been pointed out, this will often lead to an addition of the pressure rises, although this addition is confined to a narrow spot, or rather line, on the ground.

The most important factor that could seriously magnify the boom intensity, is deviations from a steady unaccelerated straight line flight. Such deviations might be acceleration in the flight path, turns in the horizontal plane and phugoid oscillations, the latter being probably the most significant. The theories for such effects are not fully developed or confirmed. They seem to indicate, however, that one will probably have to count with focussing factors of the order of 2-3. In Fig. 2, a curve for a focussing factor of 2 has been plotted.

In this connection, the following IATA questions might also be dealt with:

A-38 Is it possible that the shock waves created by operations of the aircraft will impinge on the fuselage? Will this be annoying to passengers and will it be of significance with respect to boundary layer noise or to fuselage structure integrity?

A-39 What effect would the sonic boom have on the passengers, airframe, instruments, and engines of another aircraft flying:

a) subsonic?

b) supersonic?

A-40 Are any technical means of sonic boom suppression or alleviation available or being considered as state-of-the-art refinements?

The shock waves created by the aircraft will for contemplated configurations have no or negligible effects with regard to impingement on the fuselage, annoyance of passengers or with respect to boundary layer noise. It seems also clear that the effect of the sonic bang on other aircraft, subsonic or supersonic, would be fairly small even if the aircraft pass each other at close distance, beyond, say 1,000 ft.

According to the presently recognized theory for steady supersonic flight, there are no solutions to the problem of sonic boom suppression except an extremely high slenderness ratio which, however, would probably make the aircraft unpractical.

3.3. Operational limitations due to the sonic boom.

On this subject, the following IATA questions are pertinent:

A-35 In the light of the foregoing, what requirements or limitations is the sonic boom likely to impose on operations with supersonic aircraft in relation to:

a) altitude at which transition will be made from subsonic to supersonic speed?

b) climb angle at supersonic speed?

c) cruise altitude at supersonic speed?

d) operations at supersonic speed over inhabited areas (for this purpose, what would be considered an "inhabited" area)?

e) time of day during which aircraft are operated over inhabited areas?

f) descent angle at supersonic speed?

g) altitude at which transition will be made from supersonic to subsonic speed?

A-36 Are the foregoing requirements or limitations (in Question A-35) likely to differ for operations over water or lightly inhabited areas? If so, what effect is the shock wave likely to have on ships at sea (particularly small craft), and on their instruments?

Most of these questions have already been dealt with, but the following summarizing statement might be made:

According to sonic-boom tests carried out by NASA (Ref. 3) the observers considered bangs between 0.5 lb/sq.ft. and 1.0 lb/sq.ft. as "tolerable but, to some extent, bothersome". These tests were made at day-time. In the author's opinion - as extensively motivated above - the public would never accept "bothersome" sonic bangs repeated every day. As explained, a main criterion should be sleep interruption for light sleepers and as many people have to sleep at day-time, there should be none or but a slight difference between required maximum bang intensities at day and night. As stated, the order of magnitude of acceptable bang intensity is believed to be 0.3 lb/sq.ft., and on this figure a "bang factor of safety" should be applied to account for magnifications due to phugoid oscillations and the like.

It follows from Fig. 5 that operations over inhabited areas under such requirements would be impossible even for extremely small airliners.

With regard to the definition of the concept "inhabited" area, the author maintains, as indicated in the foregoing, that even very sparsely inhabited areas must be considered as inhabited. The exact definition is, however,

not too important, because it is believed to be difficult or impossible to find two places in any one continent - for which a supersonic connection would be practical - between which a flight path can be laid out without some areas, comprising at least small communities and the like, being covered by the sonic-bang carpet.

The limitations that will have to be imposed with regard to sonic boom for operations over water are believed to be but slightly more liberal than for operations over inhabited areas. However, as mentioned above, this is a question about which the various shipping agencies and the like should at least be consulted in connection with realistic tests.

3.4. The feasibility of civil supersonic aviation considering sonic-boom limitations.

The IATA question reads:

A-37 If flight over inhabited areas at supersonic speed were not possible because of the sonic boom, would a supersonic aircraft be considered a practical proposition for airline operations?

Before commenting on this question, attention might be drawn to the fact that it is only recently that the lift component of sonic boom has been recognized and evaluated. Most of the investigations and judgements regarding the feasibility of commercial supersonic aviation seem, therefore, to be based on an underestimation of the sonic boom pressure rises that will be produced by contemplated aircraft and their operation. For example, the sonic bang intensity calculated on the basis of the volume component would for a large SST be of the order of merely 0.5 lb/sq.ft., whereas a calculation, incorporating the lift component, yields a pressure rise between 1.5 and 2.

It is obviously of great importance to check the lift-boom theory by extensive testing, in particular at high altitudes. If such tests confirm that the theory is approximately right, this would call for a serious re-evaluation of the feasibility of civil supersonic aviation with regard to sonic boom.

The Boeing Airplane Company seems to be the first aircraft manufacturer that has not only studied the sonic boom lift component but has also published some firm conclusions as a consequence of such studies. From Ref. 10 the following quotation is of interest:

"The boom created by a large supersonic airplane in high altitude cruise will likely have a higher intensity than people under the flight path of the airplane will accept. Not only will the noise level be in the range considered objectionable as defined by NASA subjective tests, but it will be at a high enough level to cause some window damage. The supersonic airplanes flying today can cruise supersonically at high altitudes and cause no particular consternation below. ------- The much larger supersonic airplane required for the transport job is not so fortunate. The effect of lift, substantially negligible for the small airplane, becomes increasingly important as airplane weight, and therefore lift, increases. The "large airplane" or supersonic transport produces a boom well up in the objectionable range at cruise altitudes of 70,000 feet or higher. It must be concluded, therefore, that the supersonic transport will be restricted to operations over water or land areas of very low population density. This, of course, is the reason so much emphasis in the preceeding discussion has been placed on North Atlantic and other ocean routes. It would appear that supersonic trips across the heavily populated U.S.A. are extremely doubtful."

This opinion seems to be somewhat more pessimistic than the short statements made with regard to sonic boom in Ref. 11 and 12.

The conclusion drawn by Boeing seems to be that civil supersonic aviation would have to be confined mainly to intercontinental routes and, furthermore, that the North Atlantic would be the backbone of the market.

In order to study supersonic North-Atlantic aviation with regard to the sonic boom, the figures 6-9 have been prepared.

Fig. 6 indicates great-circle flight paths between various European cities and Idlewild as well as the associated sonic-boom carpets, being assumed to be 50 miles (80 km) wide. This width corresponds, in fact, only to the core of the carpet, comprising en-route bang intensities between 0.5 and about 1.6 lb/sq.ft., the total width of the carpet having pressure rises above 0.3 lb/sq.ft. being about 90 miles (150 km) (Fig. 4). Figs. 7 and 8 are enlargements of Fig. 6 for the American and European ends of the routes.

As is illustrated by these figures, the great-circle sonic-bang carpets pass over appreciable land areas on the American side, and on the European side vast portions, not least densely populated areas, would be covered by the bang carpets.

If supersonic flying over land will be prohibited, there seems only to be two possible ways of arranging supersonic cross-Atlantic flying. One is to approximately follow the great-circle routes from cities in Europe to cities in America, but to fly subsonically between the cities and the coasts of the

two continents. This might be technically feasible (although it would probably call for a variable configuration aircraft) but is believed to be uneconomical.

The other solution would be to lay out a main route between, for instance, Idlewild on the American side and a "supersonic airport" on the European side in such a way that the sonic-bang carpets fall entirely over water. Such a scheme would, of course, have the disadvantage that most of the traffic on a main Atlantic route would have to be fed by subsonic airliners from cities in Europe and the United States other than those selected to have supersonic airports. Passengers would often have to change aircraft and the supersonic airports would, of course, be accordingly more crowded. This arrangement is illustrated by Fig. 9, where Paris has been chosen as the European supersonic airport. The trip length of this route is about 3,300 nautical miles. It is assumed that the middle part of the Atlantic crossing would take place in four main channels, for instance 50 miles apart, i.e. the width of boom carpets comprising intensities above 0.5 lb/sq.ft.

In order to get an idea of the number of sonic bangs that would occur at any place in this 200 miles wide band, the following assumptions are made. During 1959 the North-Atlantic air traffic reached a total of 1.5 million passengers. If it is assumed that the annual expansion of the traffic is, on the average, 12% during the sixties, 10% during the seventies and 8% during the eighties, then about 12 million passengers would fly the North Atlantic in 1980 and 26 millions in 1990. If it is, furthermore, assumed that 50% of the traffic is supersonic and that each supersonic airliner on the average carries 100 passengers, there will be about 160 supersonic flights over the North Atlantic per day in 1980 and 360 in 1990. These flights would require 40 and 90 SST, respectively, if each makes 4 single trips per day, and twice as many, if each aircraft only makes 2 single trips per day (see Section 4.1). If it is finally assumed that 75% of this supersonic traffic goes on the suggested New York - Paris route, there will, on the average, be 120 bangs per each 24-hour day in 1980 and 270 per day in 1990 in any cross-section of the 200 miles band and one fourth of that at any point in each 50 miles bang carpet.

These bangs will, however, not be evenly distributed over the day. It follows from the study in Section 4.1 that the peak frequency might in 1980 amount to about 6 bangs per hour in each of the four 50 miles bang carpets, if each SST makes 4 single trips per day, and to about 4 bangs per hour, if

each SST only makes 2 single trips per day. These peak values will, of course, be considerably higher in 1990.

As suggested above, it is mainly for the shipping agencies to judge whether a bang frequency of the indicated order of magnitude would be acceptable. It seems, however, also worthwhile to consult fishermen and private yacht-owners operating in the waters east of Long Island and in the western part of the English Channel between Cornwall and Brittany. In doing so, the increase in bang intensity, to about 2.0 lbs/sq.ft., during the supersonic part of the climb - within a distance from the airport of some 400 miles (600 km), see Fig. 3 - should, of course, be observed.

It might be noted that if the supersonic Atlantic traffic were instead distributed over a number of supersonic routes between Europe and the U.S.A. plus Canada, the maximum bang frequency would decrease but the total area of the Atlantic which would be affected by sonic bangs would considerably increase. It is doubtful whether this would be less harmful for the shipping and fishing businesses.

In conclusion it may be stated that on the basis of present knowledge, supersonic aviation, because of the sonic boom, seems quite unfeasible for operation over practically all land areas of the earth. The question of whether supersonic aviation can be considered a practical proposition is then reduced to the question of whether over-water supersonic operation between the continents would be feasible. It would be premature to venture a definite view on this question before extensive over-water tests have been made in order to obtain the reactions of boat passengers and crews. The author believes, however, that the disturbances will be so serious, with the contemplated size of the aircraft and flight altitudes, that it is anyhow doubtful whether the possible gains by flying supersonic over the oceans would outweigh the disadvantages.

3.5. Suggestions regarding special sonic-boom tests and the recording of boom occurrences.

As has been emphasized above, sonic-boom tests are needed for assessing both acceptable bang intensity limits and the actual intensities that can be produced under various circumstances. These two main objects of the tests can to a large extent be combined. As there will be no civil supersonic aircraft available for many years, the tests will have to be performed with military supersonic fighters and bombers.

The following tentative thoughts on a typical test program are submitted:

1. A series of steady level supersonic flights should be made, beginning at very high altitudes and successively coming down to as low altitudes as are compatible with the supersonic performance of the aircraft. The tests should aim at checking - or modifying - the steady flight sonic boom theory as well as studying the influence of atmospheric conditions and the reflection factor and echoing effects with various types of terrain - including mountains - and size and disposition, etc., of buildings. Furthermore, the reactions of observers and the public should be studied as well as imposed damage to property.

2. These straight constant-altitude fly-past tests should, for the higher altitudes, be made over all conceivable types of the country with regard to the density of population, including cities, as well as over sea, and they should be made both by day and by night.

3. The night-flight tests should be made under medical supervision to assess sleep interference effects on various categories of people under various conditions of back-ground noise, open or shut windows, etc. At the lower altitudes, the tests should be made over more sparsely populated areas, so that not too many people are awakened.

4. A series of steady fly-past tests during night-time should be repeated frequently so as to determine any cumulative physiological effects.

5. For the steady-flight day-time tests it will also be necessary to conduct the low-altitude part of the program over sparsely populated areas in order to limit the window breakage and other damage to property.

6. In order to assess the results of the very high pressure rises which may occur because of focussing effects, a portion of the steady flight tests should be made at very low altitudes over completely uninhabited areas and/or over sea and the damage effects should then be studied entirely on an experimental basis.

7. In addition to these steady-flight tests, an extensive amount of testing should be made with various types of unsteady flight - turns, accelerations and, most important, phugoid oscillations. Moreover, the effect of climb and descent angle should be studied.

8. All the tests should be supervised and evaluated by medical and acoustic experts.

9. For some of the tests conducted over inhabited areas, extensive Gallup interrogations should be made to assess the reactions of people both with regard to sleep interference and disturbances by day.

Adequate testing of this type and scope lies apparently in the interest of the people so that they are able to form an opinion in advance about acceptable sonic-bang intensities and frequencies. The testing should also be of great value to the airlines, as pointed out in the Introduction.

It, therefore, seems desirable that all countries owning military supersonic aircraft should conduct tests of this type. Because of the nature of the

testing, it appears appropriate that ICAO should take the lead in initiating or stimulating such tests in as many of the Member States as possible and should therefore suggest a detailed test program, etc., so as to get a certain amount of consistency in the evaluation. All information obtained should, of course, be submitted to ICAO and other agencies interested in the subject, such as IATA and the national aviation authorities. However, there should, of course, be no objection to any one country starting systematic sonic-boom tests before ICAO has approached the various governments.

As it is well known that in many countries severe "sonic-boom explosions" have occurred rather frequently in the last few years, such happenings could obviously be utilized as a valuable source of information. It is therefore suggested that ICAO should form a special "Sonic Boom Evaluation" Committee which should collect and, as far as possible, evaluate this information. The various Member States should make records of such occurrences and send the information to the ICAO Committee.

In order to enable the Committee to evaluate it on a standardized basis, the information should be as complete as possible and comprise non-secret information regarding aircraft weight, flight altitude and attitude, atmospheric conditions, etc., as well as the nature and extent of the damage to property and disturbance of people. After complete evaluation, the ICAO Committee should submit "Sonic Boom Reports" to all the Member States.

4. POTENTIAL IMPLICATIONS. FUTURE OUT-LOOK.

4.1. Utilization and scheduling, in particular for North-Atlantic flights.

One of the IATA questions pertinent to the subject of scheduling reads:

G-2 Is it believed that competitive scheduling in terms of arrival and departure times will be more important with supersonic air transport or will this aspect be less significant?

There are also a number of other IATA questions dealing with the same or related subjects, such as travelling times preferred by the public (G-1, G-2, G-6, G-9), turn-round and transit times (G-11).

One approach to the problem of optimal scheduling so as to achieve a maximum utilization of aircraft is first to consider public preference with regard to departure and arrival times and then to find out to what extent a certain proportion of the potential passengers would fly at less convenient

times of the day or the night, if the fares were suitably reduced. With this approach as a back-ground, three examples, illustrated in Figs. 10-12, will be studied. They are primarily thought of as representing the case of a concentrated or main supersonic route between Paris and New York, as suggested above (Section 3.4), but most of the views and conclusions would be valid also for any other east-west supersonic route of about the same distance, 3,300 nautical miles.

In Ref. 13, Mr. B. Holmer, Vice President, Engineering, SAS, has pointed out the adverse effect of the time difference between U.S. and Europe with regard to scheduling for preferred departure and arrival times. He assumes "that passengers do not like to depart and arrive after midnight or before 8 o'clock in the morning". The author believes that this assumption can be somewhat qualified in that a passenger might not object to arriving as early as 7 a.m., but not much earlier, provided that he has had a full night's sleep. Furthermore, most passengers probably dislike arriving after 23.00 hours, because of the time it takes to be cleared through the airport and travel to the home or the hotel.

It is most important that the scheduling should be such that the passenger has a chance to a reasonable amount of sleep each night, either on board or the nights before and after the flight. This seems to put supersonic transatlantic flights at a disadvantage compared with subsonic flights. With the present subsonic jets, the passenger can, during a night's flight, normally sleep for some 4-5 hours of the 7-8 hours flight time, whereas on a supersonic night flight, lasting about 2 1/2 hours, there would be practically no chance to sleep during the flight. As is illustrated by Fig. 10, a supersonic night flight from New York to Paris would cover the whole night because of the time difference, and for a supersonic night flight from Paris to New York the passenger would be compelled not only to board the aircraft in the night but also to leave the aircraft in New York at a very inconvenient hour, either in the middle of the night or very early in the morning.

If we thus to begin with, study the scheduling for day-time flights between Paris and New York, Fig. 10 illustrates how a fleet of aircraft can perform on the average 4 flights per day, provided that the flight time is 2 1/2 hours and the turn-round time is as short as 1 hour. It might be assumed that half the fleet takes off from Paris and the other half from New York, both halves returning to the home airport in the same day. Applying the example of Section 3.4, the fleet would comprise 30 aircraft in 1980 and

nearly 70 in 1990. Each line in the figure might then represent 5 and about 11 SSTs, respectively.

It should be observed that with this scheduling - in spite of the short turn-round time - it seems impossible, to avoid arriving in New York before 7 a.m. with any of the morning flights from Paris. Furthermore, the morning flights from New York would have to take-off before 8 a.m. and the last flights back to New York would have to leave Paris after 23.00 hours. These arrival and departure times would not be too popular, and they are therefore indicated by question marks in the figure. Obviously, this scheduling is rather tight at both ends of the day and would require turn-round times of one hour, which it may not be possible to achieve. Added to this, it requires that in 1980, 30 aircraft (in 1990, 70 aircraft) must land in one hour and take-off again within the next hour.

Fig. 10 also shows that the problems are not significantly lessened if each aircraft makes only three flights a day instead of four, because the three flights originating in New York and terminating in Paris must be squeezed in between 07.00 hours in New York and 23.00 hours in Paris. This would necessitate not only a turn-round time of merely one hour, but also a 33% higher dispatching and reception frequency at the airports.

It seems therefore, that a supersonic airliner operating between Paris and New York will not be able to make more than two flights per day (1 return flight) if it is to operate on a schedule convenient for the passengers. Such a schedule is illustrated in Fig. 11. The number of aircraft would have to be increased, but the schedule permits turn-round times of two hours and a greater spread in time between the flights and this should be more economical for the airlines. In addition, the flight time has been increased to three hours to give a margin permitting, for instance, supersonic climb to be postponed to a high altitude to reduce the effects of the sonic boom.

For comparison, Fig. 12 shows a possible schedule for a subsonic jet aircraft operating over the same route. Flights from Paris to New York would take place by day and the return flights by night. In this way, each aircraft could operate two single flights each day (24 hours) and still allow 8 hours on the ground for turn-round and maintenance. The turn-round time would be between 2 and 6 hours in the example. If flights by day from New York to Paris were required, a somewhat larger fleet of aircraft would be needed.

The important conclusion to be drawn from this analysis is that it does not seem to be easily possible to utilize a supersonic transport for more flights over the Atlantic than are possible today with subsonic jets. For the operating cost of the supersonic transport to be of the same order as that of subsonic airliners it is necessary that, on the average, the ratio of the productivities of the two types (aircraft or passenger miles per day) should be roughly the same as the ratio of the speeds.

There are two possibilities for increasing the utilization of a fleet of cross-Atlantic supersonic transports. One is to use them for other routes such as from New York to South America, but it seems doubtful whether this can be economical or efficient if supersonic flights are not permitted over land. The other possibility is, of course, to persuade people to fly supersonic at night between New York and Europe at a reduced fare, as mentioned above. It has already been explained that supersonic night-flights would be rather inconvenient, because they would in most cases almost completely prevent the passenger from getting any sleep, in particular on flights from New York to Europe. This being so, the fares for supersonic night-flights will have to be considerably lower than those for night-flights with subsonic jets, because such flights would be more convenient, as it is usually possible to sleep for a considerable part of the 7 hours it takes to travel from New York to Paris.

Finally, it should also be noted that even with supersonic speed it is hardly possible to fly from New York to Paris in day-time without spoiling the whole day as a working day.

4.2. The technical/economical relationship between subsonic and supersonic developments.

IATA questions:

G-42 To what extent is it expected that the operation of low cost/low fare subsonic jet aircraft simultaneously with supersonic aircraft may eliminate the profitability of the latter, or is it expected that the development of traffic and the need for high speed transportation will provide an adequate demand for supersonic air services? ------

G-47 Although planning for the supersonic aircraft is still in the relatively early stage, it must inevitably affect the priority given to further development of subsonic equipment. Would, for example, a manufacturer now consider initiating an entirely new design of long-haul subsonic aircraft or even a radically different model of an existing

basic type? Are the manufacturers likely to continue development efforts on existing subsonic jets?

The current interest in spectacular supersonic transport projects has tended to obscure the immense potentialities of subsonic aircraft developments. It should, however, be realized that all airliners, delivered or on order up to now, represent, by and large, one and the same level of the art of aeronautics (excepting the moderate step forward by the introduction of turbo-fan engines).

There can be no doubt that the next generation of subsonic airliners will display appreciable technical improvements, but they will probably not employ new basic design principles. For the "third generation", however, there should be great possibilities that some quite radical advances will be introduced, for instance along one or more of the following lines of development:

(a) Boundary layer control for the purposes of both increasing the lift coefficient at take-off and landing and reducing the drag.

(b) Jet flap, and similar developments, possibly modified so as to use only the cold fan air from turbo-fan engines for blowing through the wing.

(c) V/STOL aircraft, for which dozens of principles are being studied, and more are likely to appear.

All these developments are highly promising and important. In addition, the V/STOL development has, in fact, become nothing less than a necessity. Not only will it imply a tremendous growth of, in particular, short-haul aviation of all kinds; it is the only practical way of solving the problem of the congestion at airports, because it will unload existing airports by moving a large portion of the traffic to smaller and cheaper ones. Otherwise most existing airports will become inadequate in the near future because of the growth of aviation in general and the increasing proportion of short-haul aviation (including commuter-traffic) in particular. Short-haul aviation involves many more movements for a given annual utilization than medium and long-range aviation.

It might be pointed out that all the three indicated lines of development call for tremendous efforts and large investments in order to be successful. If they are successful, they will radically change the potentialities of aviation

and make it a means of mass transportation both for people and freight to an extent that is difficult to visualize today. Developments such as boundary layer control and the jet flap will, in particular, make possible great reductions in air fares, probably to half their present levels and possibly even lower.

Considering now the relationship between such developments of subsonic aircraft and a commercial supersonic transport program, only three main views will be expressed:

1. The prospects of successive reduction of the operating cost are inherently much greater for subsonic than for supersonic aircraft. One of the main reasons for this is that reduction of the friction drag by means of boundary layer control will mean a greater percentage reduction of total drag for the subsonic aircraft, because the friction drag is a higher proportion of total drag for subsonic than for supersonic aircraft. Boundary layer control for achieving laminar flow is also probably easier to arrange for subsonic than for supersonic aircraft. The same applies with regard to obtaining high lift coefficients for improving take-off and landing performances. As illustrated by Fig. 13, it seems inevitable that, during the next 2 - 4 decades, the difference between the operating costs of supersonic and subsonic air transportation will increase continuously.

2. There can be little doubt that the indicated subsonic developments will be seriously delayed if a supersonic transport program is launched or even if there is merely a wide-spread opinion that supersonic transports will have to come about in a fairly near future. The reason for this is not so much the diversification of efforts on the part of aircraft manufacturers, because only a few of them would have to concentrate on a supersonic development. The main reason for the adverse effect on subsonic development by a supersonic program is probably that many of the airlines would feel compelled to buy supersonic aircraft. This would not only impair their economical possibilities of procuring radically new subsonic equipment as well, but it would also make such airlines unwilling to acquire fleets of subsonic aircraft with lower operating cost than their supersonic fleet, as this would imply a competition even within the company, which might lead to uneconomical utilization of their supersonic aircraft.

3. It must be observed that although a supersonic transport program will seriously hamper the indicated subsonic developments, the efforts on supersonic will not prevent the subsonic development to come about; the only possible effect will be a delay. This implies that, even if the supersonic airliners by virtue of their speed could favourably compete with the subsonic aircraft around 1970, supersonic aviation is likely to meet increasingly severe competition from low-fare subsonic aviation in the subsequent decades (Fig. 13).

There are, of course, many factors other than operating cost that must be considered when studying the mutual influence of supersonic and subsonic developments, such as the need for improving regularity considering the possible difficulty of incorporating supersonic aviation into the subsonic traffic pattern without impairing regularity.

In a class by itself with regard to importance is, however, safety. It can easily be foreseen that, with the present accident rate, the absolute number of air accidents will be intolerably high a few decades from now. Considering the growth of all branches of aviation, air accidents of newspaper headline size would be daily occurrences, and it is the absolute number of disastrous air accidents that govern public confidence in aviation - not the accident rate (Ref. 15).

Because of this, there is an urgent need for a rapid decrease of the relative accident rate. This is indeed a formidable task and calls for some radically new approaches to the aviation safety problem, in particular air traffic control. It is especially important to realize fully the impact of the growing congestion around cities and their existing and new airports that will be an inevitable consequence of the future growth of short-haul aviation. It is maintained that the safety problem is the most important task that faces the aeronautical sciences, and there can be little doubt that the safety problem would be made still more difficult by the premature introduction of supersonic aviation.

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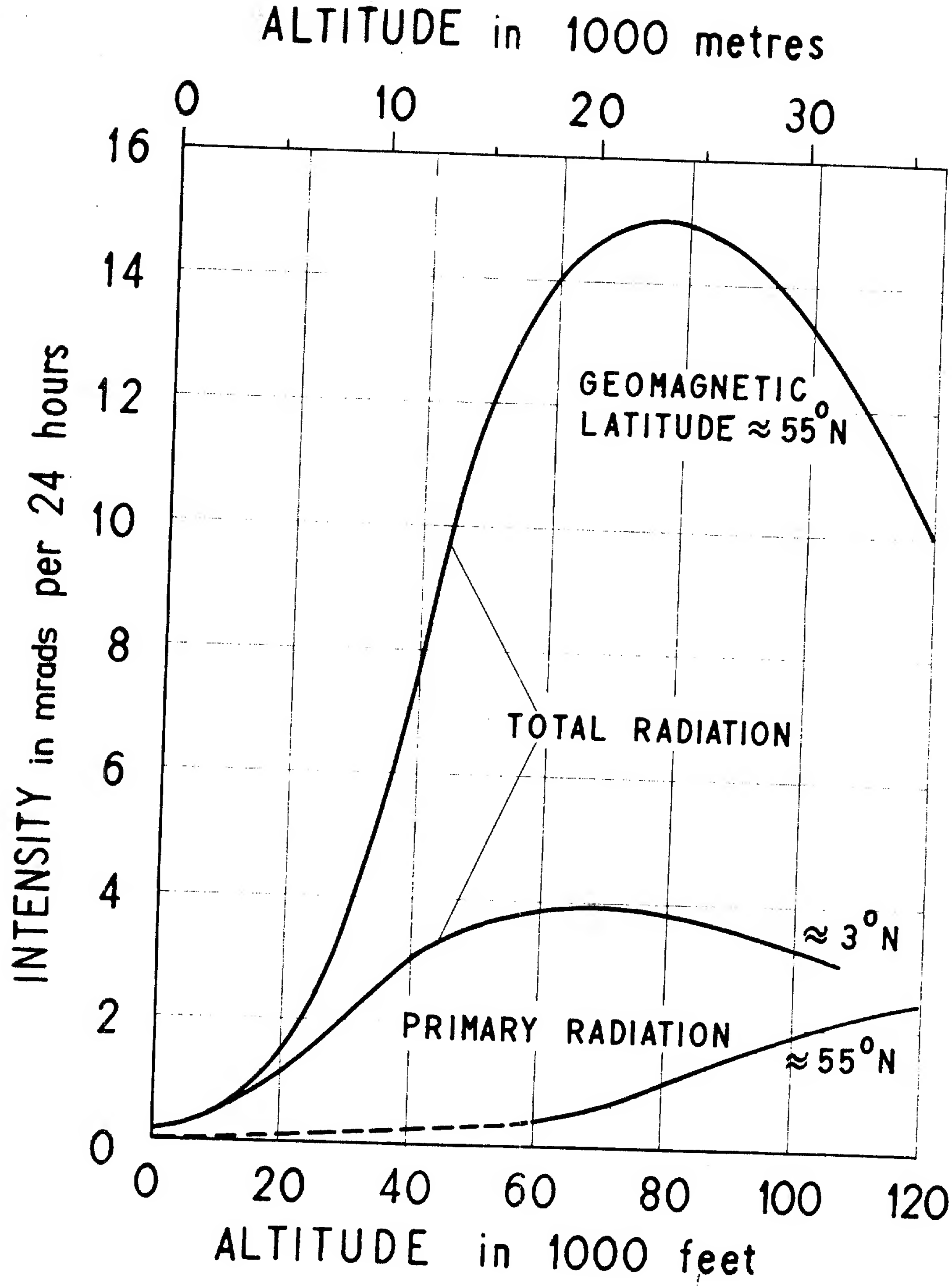
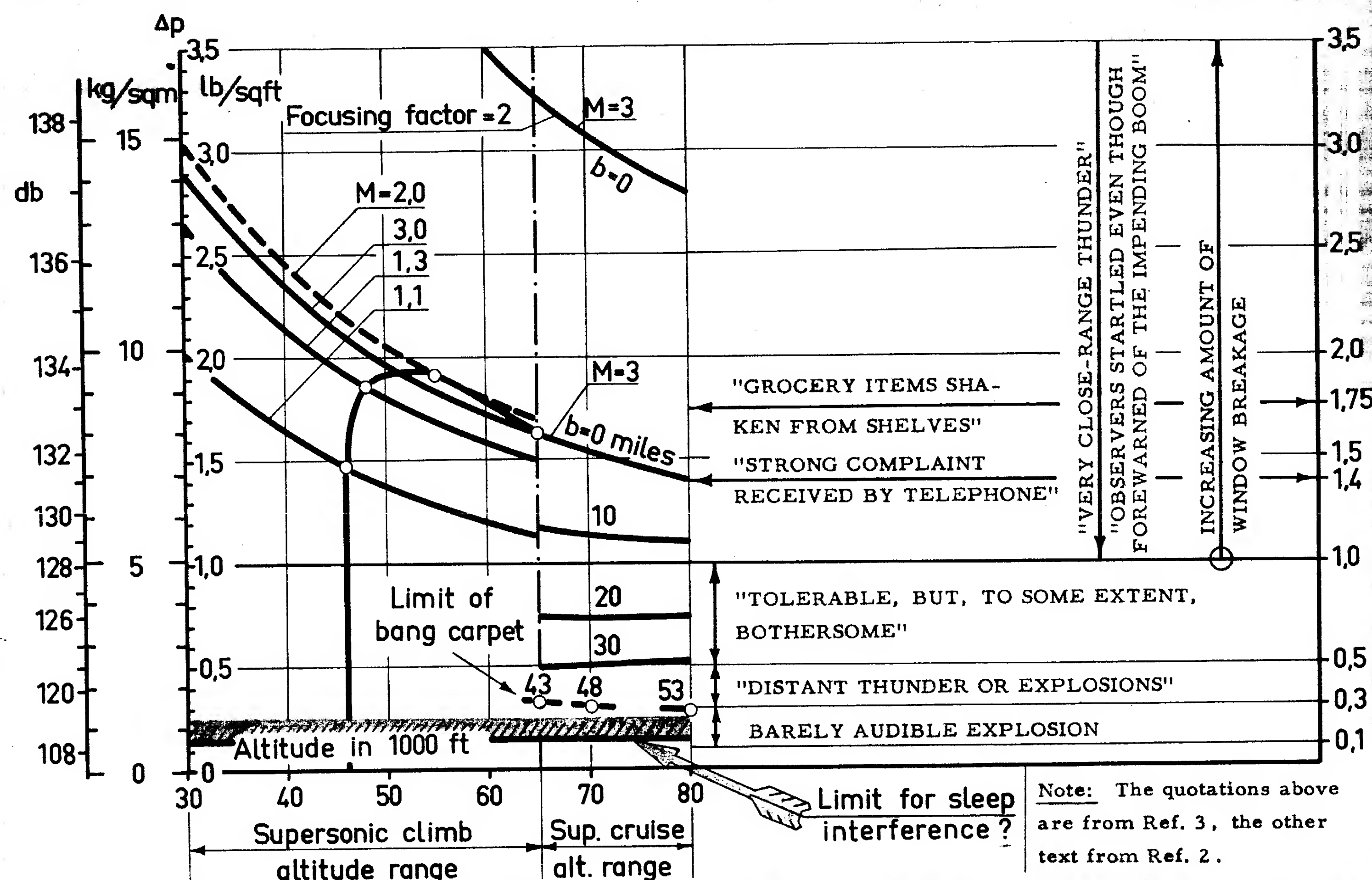


Fig. 1. Ionisation intensity of cosmic radiation at various altitudes; from: Schaeffer, H. J.: The Journal of Aviation Medicine, 23, 1952, p. 334. The intensity is expressed in mrad per 24 hours. (One mrad = 1/1000 rad, one rad corresponds to an energy absorption of ionizing radiation of 100 ergs per gram in any tissue or medium.)



Note: The quotations above are from Ref. 3, the other text from Ref. 2.

Fig. 2. Pressure rise vs. altitude for an aircraft weight of 400,000 lbs. For the supersonic climb altitude range, the curves indicate the pressure rise straight below the flight path (b = 0) for various Mach numbers. The intersecting curve corresponds to the example of Fig. 3. For the supersonic cruise altitude range, the curves indicate the pressure rise at different lateral distances, b, from the flight path.

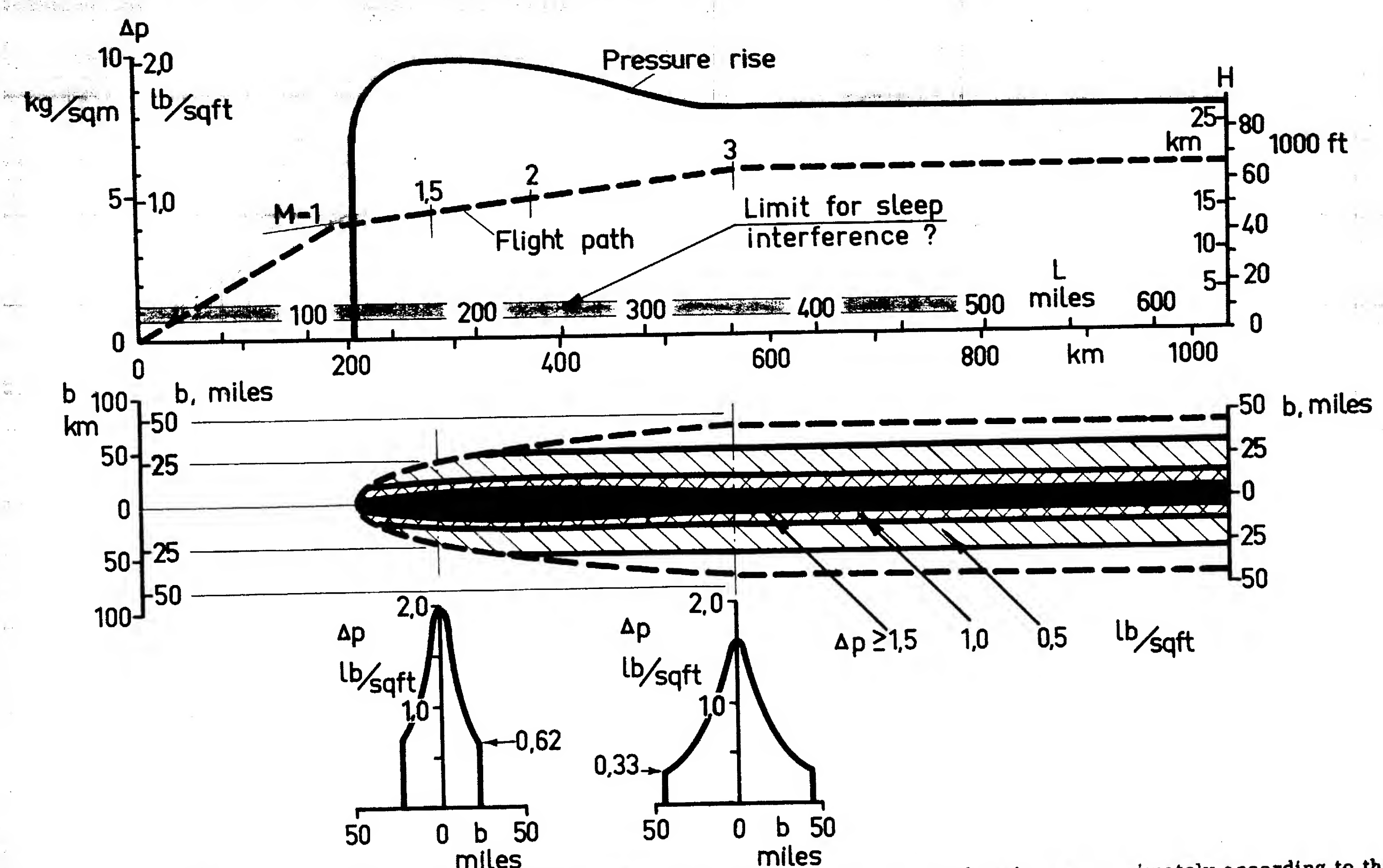


Fig. 3. Sonic bang carpet for an SST of 400, 000 lbs. weight for climb and initial part of cruise, approximately according to the flight profile suggested in the NASA TN D-423. It should be observed that the altitude scale for the flight path in the upper figure is different from the length scale of the lower figures.

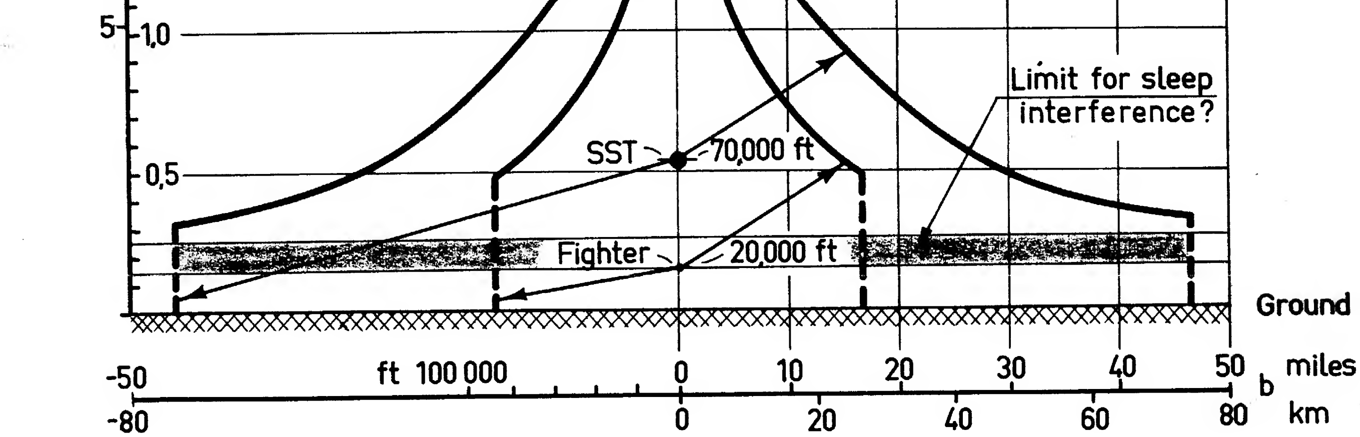


Fig. 4. Sonic bang width and pressure rise profiles for sonic bang carpets of an SST of 400, 000 lbs. and M = 3, flying at 70, 000 ft., and a military aircraft of 25, 000 lbs., flying at 20, 000 ft and M = 2. Both produce about the same maximum bang intensity below the flight path. The altitudes of the two aircraft are indicated in the same scale as that for lateral spread on ground.

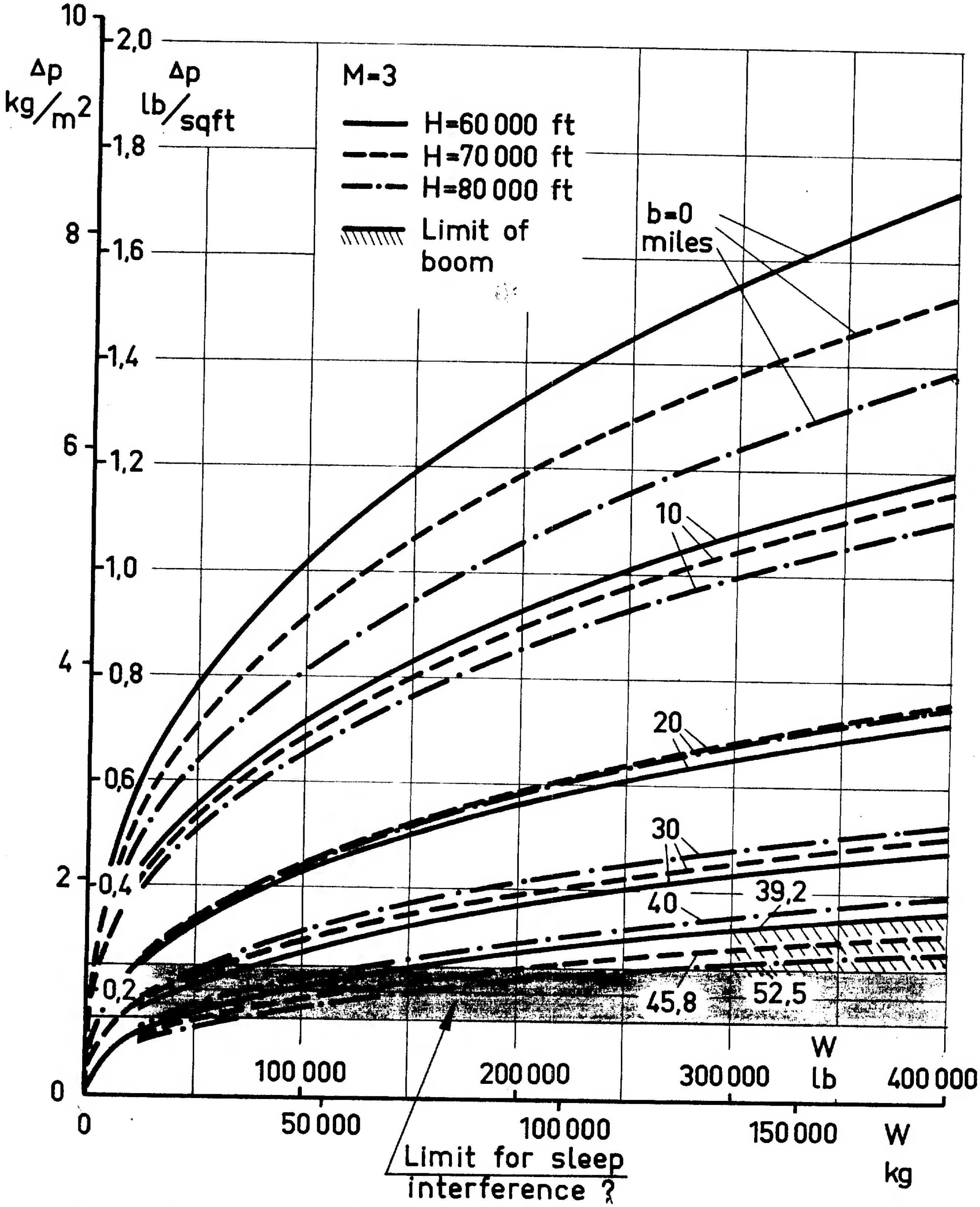


Fig. 5. Pressure rise vs. aircraft weight and cruise altitude for various lateral distances from the flight path.

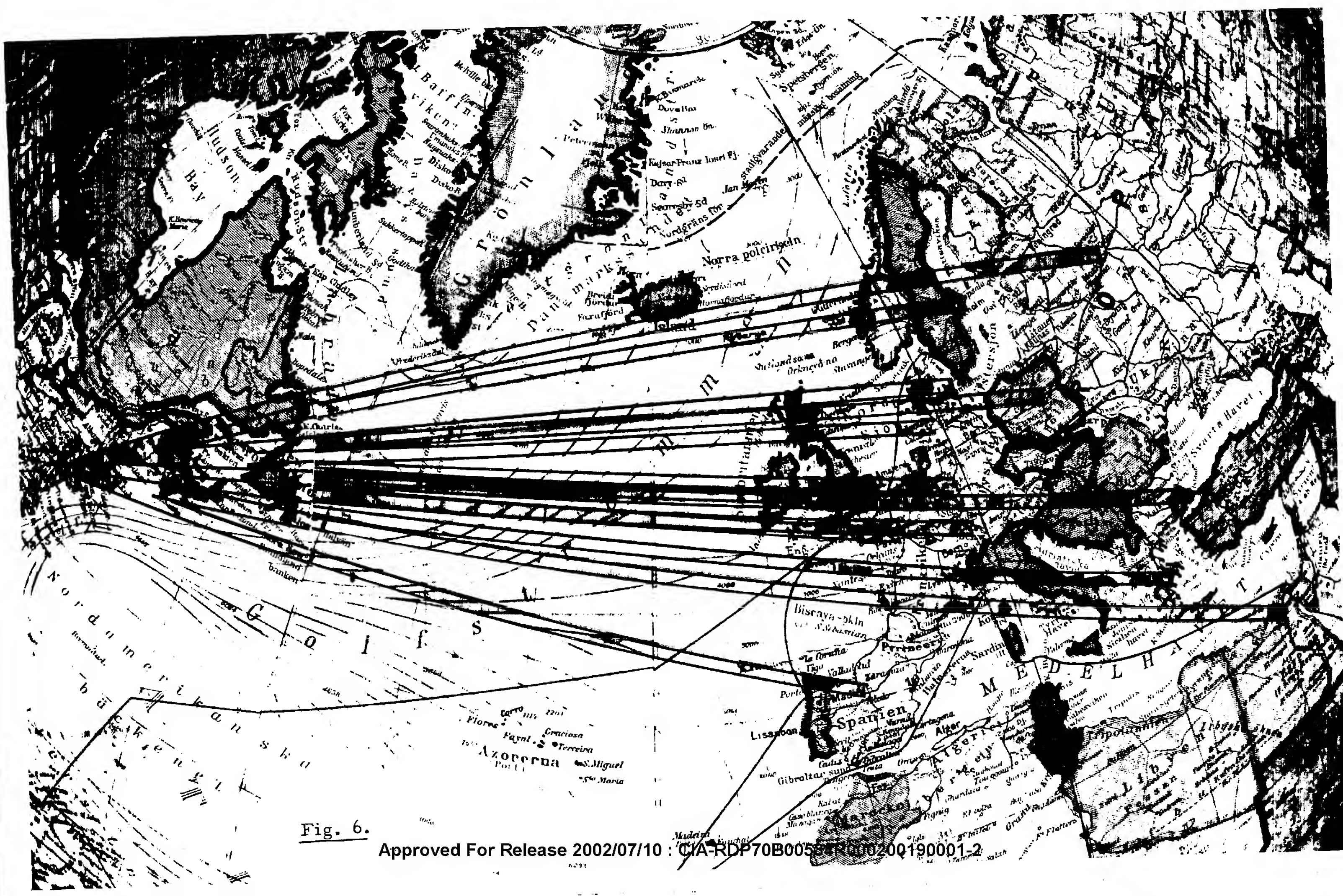

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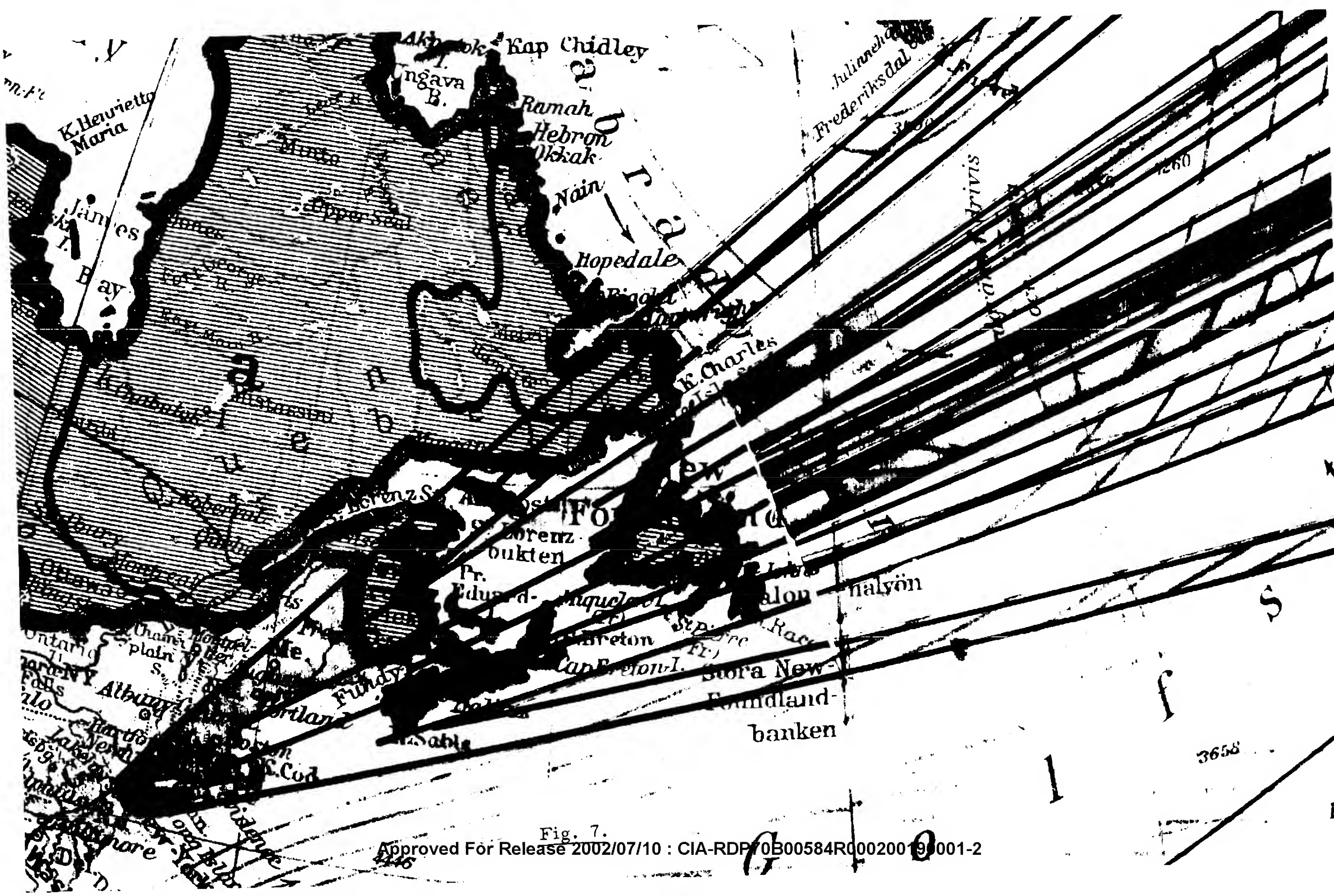
Fig. 6.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Lorenz-bukten
Pr. Edward
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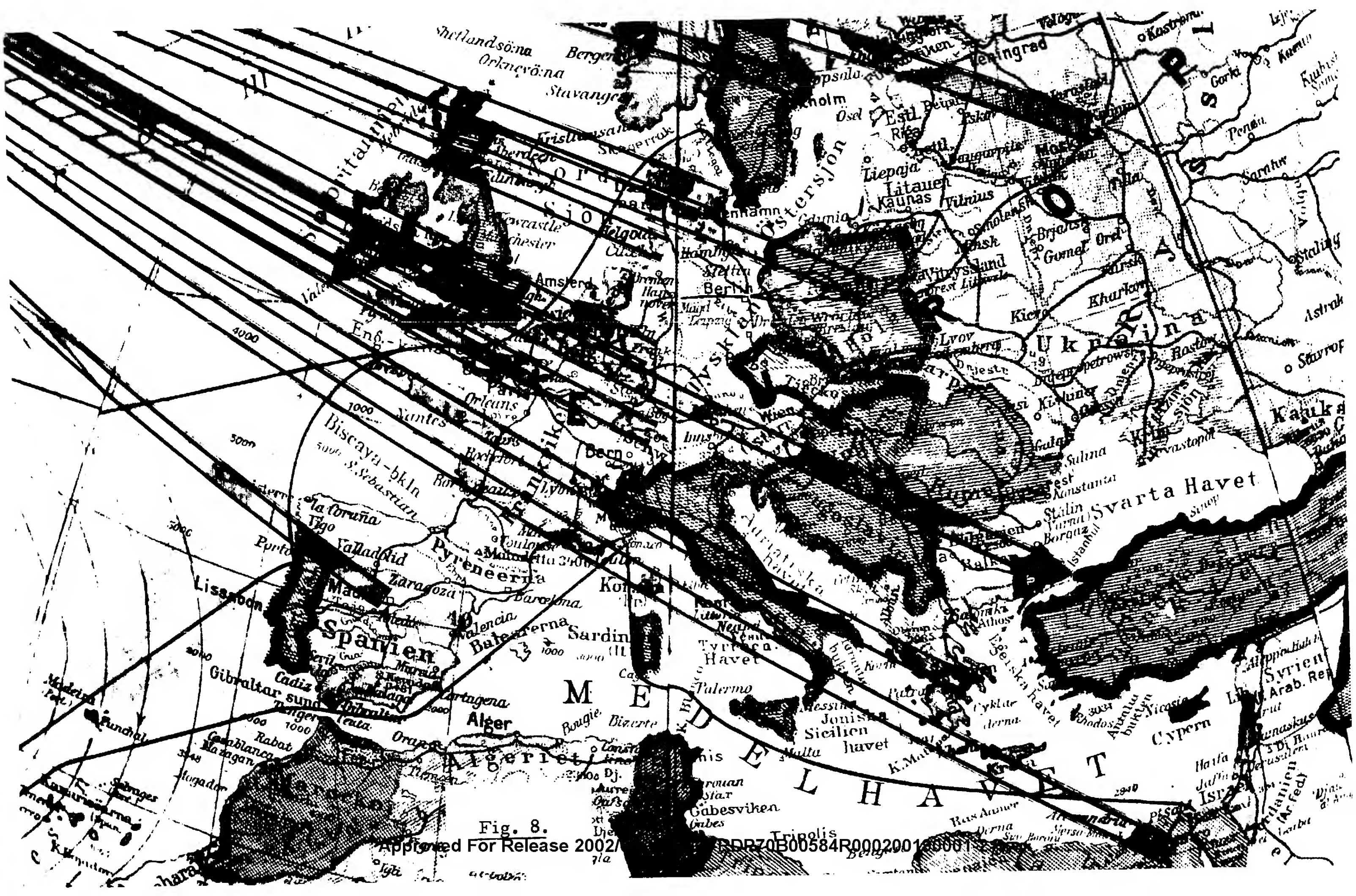
Fig. 7.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Tanger
Ceuta
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Oran
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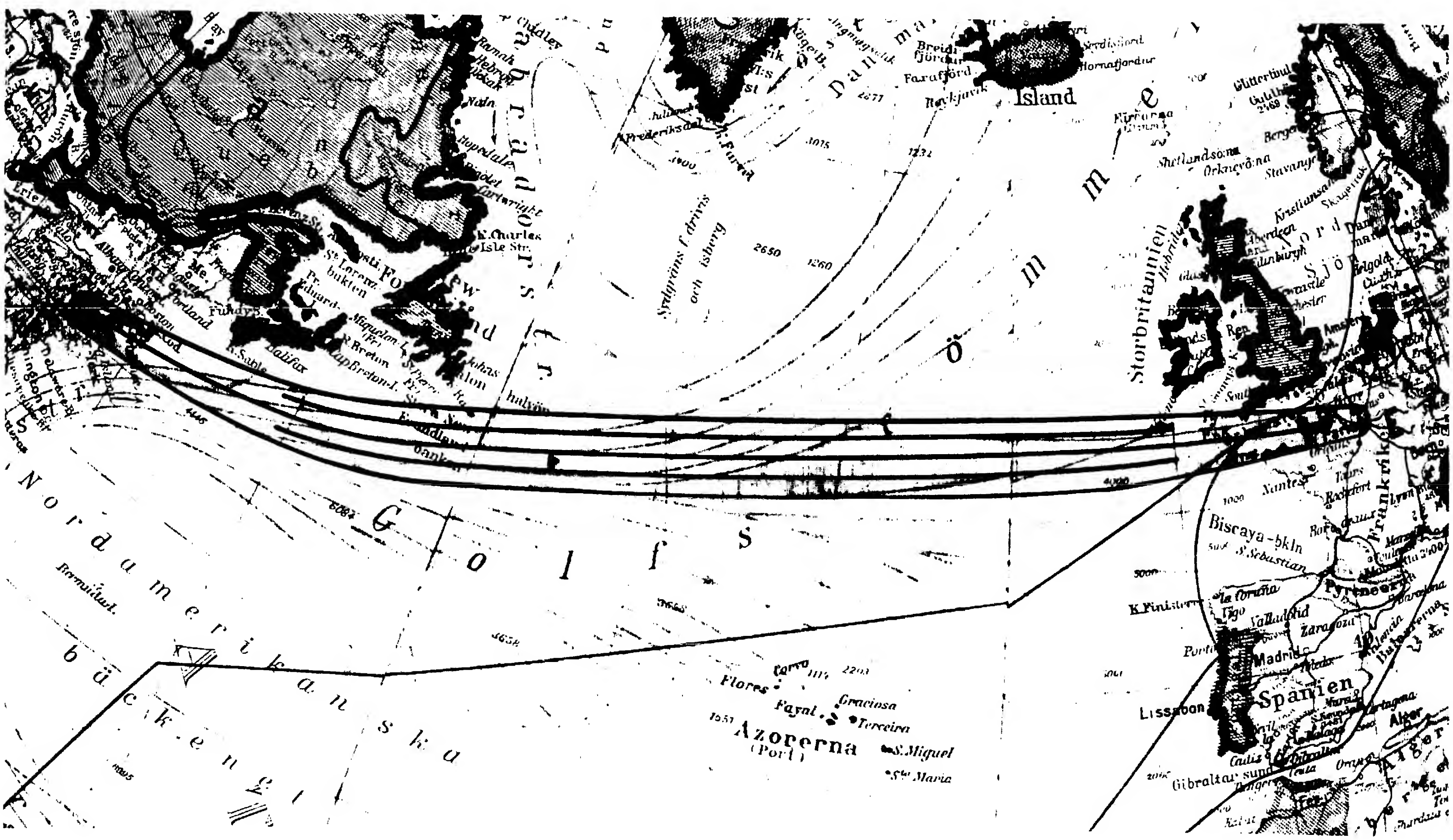
Egeiska havet

Fig. 8.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Edinburgh
Aberdeen
Nordsjön
Sydgräns f. drivis och isberg
K. Charles
Belle Isle Str.
Halifax
K. Sable
Kap Breton I.
Boston
Fundy-b.
Newfoundland
Nantes
Rochefort
Frankrike
Biscaya-bkln
S. Sebastian
Pyrenéerna
K. Finisterre
La Coruña
Vigo
Valladolid
Zaragoza
Madrid
Spanien
Lissabon
Gibraltar sund
Cartagena
Alger
Flores
Corvo
Fayal
Graciosa
Terceira
Azorerna
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Nordamerikanska bäckenet
Golfs

Fig. 9.

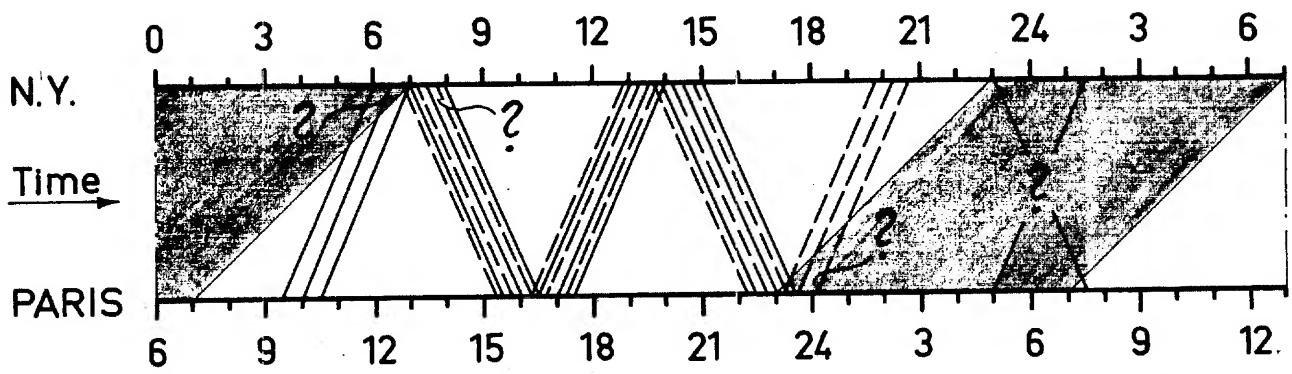

Fig. 10. Scheduling for four single supersonic flights (two return flights) per supersonic aircraft per day between Paris and New York. Shaded areas indicate night-time. Flight time 2 1/2 hour, turn-round time 1 hour.

——— aircraft originating from and returning to Paris
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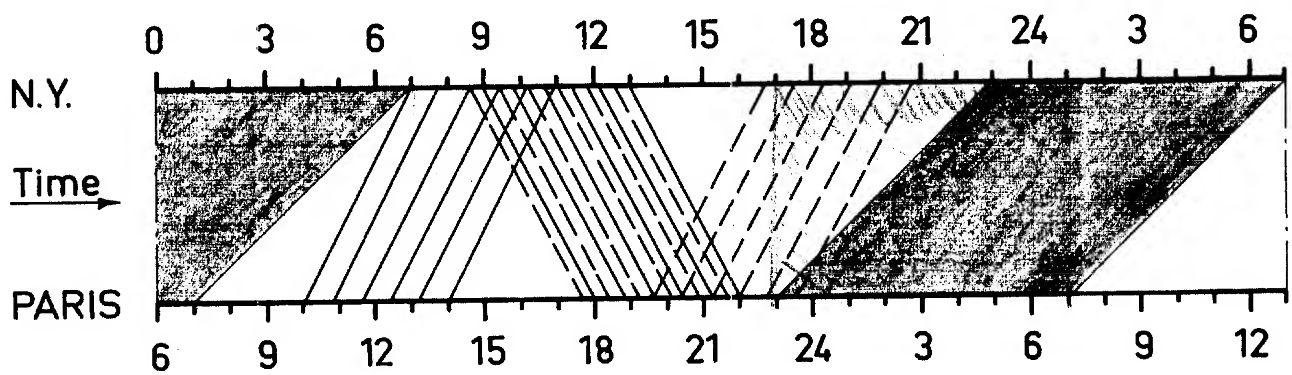

Fig. 11. Scheduling for two supersonic single flights per aircraft per day. Flight time 3 hours, turn-round time 2 hours.

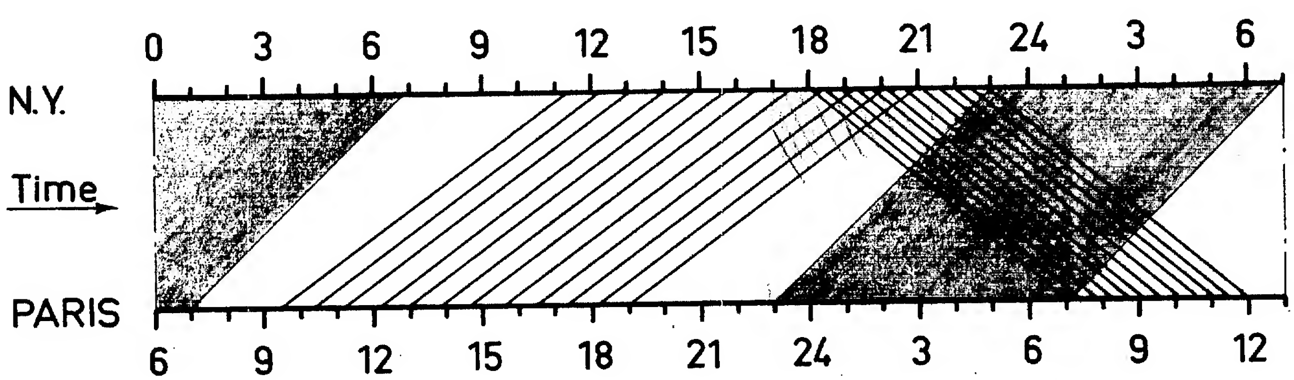

Fig. 12. Scheduling for two subsonic single flights per aircraft per day. Flight time 8 hours from Paris to New York and 7 hours from New York to Paris. Minimum turn-round time 2 hours.

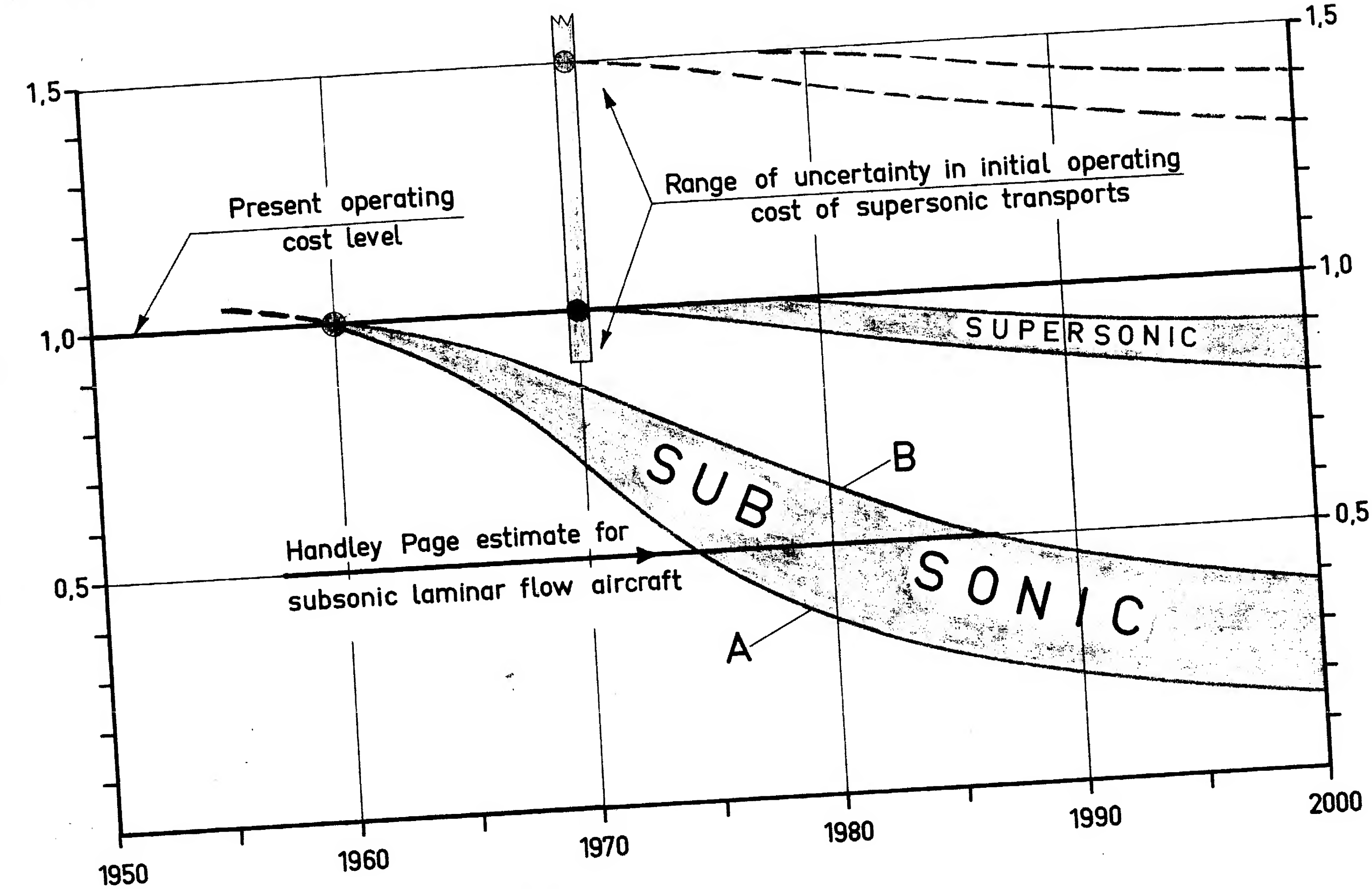

Fig. 13. For text, see following attached sheet.

Fig. 13. The upper shaded area indicates possible development of operating costs of supersonic air transports based on the assumption that the cost will be the same as that of the present subsonic jets. The initial costs may be higher, as many maintain - broken lines. The lower shaded area illustrates the corresponding development for subsonic airliners. If all efforts are devoted to subsonic development, operating cost might be expected to decrease as shown by curve A. If, however, supersonic aircraft are introduced, the subsonic operating cost will decrease much more slowly (curve B), see Section 4.2. In any case the difference in cost between supersonic and subsonic operation will probably increase continuously with time.

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Attachment 1
to FFA Memo No. PE-11

Translation

COSMIC RADIATION AND MANKIND

by

Martin Wrete
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Published in "Dagens Nyheter", Stockholm, 7th March 1958.

The cosmic radiation from outer space to which mankind is continuously exposed, is mainly of the type referred to as ionizing, and, as with other forms of ionizing radiation, such as X-rays, must have a biological influence on human organisms as well as on animals and plants.

The total ionizing influence of cosmic radiation on all animal organisms has been calculated to be a maximum at a height of approximately 23,000 metres (75,000 ft) above sea-level, and diminishes as it passes through the atmosphere, so that at ground level it is approximately 0.3 - 0.5 % of the maximum value. The intensity of the radiation not only varies with height, but also changes with latitude: it is strong in Sweden's temperate zone. Occasional local amplifications can appear at ground level, so-called cosmic showers. Another fact of importance is that when primary cosmic radiation passes through a shielding mass consisting of a substance of high atomic weight, e.g. a metal, there arises a "cascade effect"; the very high-energy radiation components are transformed to a large number of components with lower energy, which is still large enough to influence the living cell.

During the last decades rather extensive research has been conducted, particularly in the U.S.A., regarding the biological effects of cosmic radiation. At sea-level the radiation is so sparse that one cannot expect any obvious results within a reasonable period of time. One must be content with regarding this ever-present weak radiation as a probable reason for some of the "spontaneous" mutations which at times appear in human beings, animals and plants; it has also for a considerable time been referred to as one of the factors which are believed to be a possible cause of cancer.

However, by establishing a cascade effect with a metal plate of, for example, 13 mm thick lead, one can amplify the radiation so appreciably that biological results can be observed even after a moderately short time.

Reprinted from "New Scientist," Volume 9, Pages 460-462

Should supersonic airliners be permitted?

Or should their development be postponed until more is known about the potential effects of sonic booms on the population below, and of cosmic rays on the passengers? The author, a frank advocate of postponement, indicates other lines of development which he considers more urgently desirable

by Bo Lundberg
Director, Aeronautical Research Institute, Sweden

It is generally believed that all technical problems involved in the design and operation of supersonic commercial aircraft—at Mach number anywhere between 2 and 3.5—can be solved in the near future, even if they are not solved today. The topical question widely discussed is, therefore, *when* should this kind of aviation be introduced? Having in mind two specific problems of a fundamental nature, which are completely new to civil aviation, I am personally not convinced—not yet, anyhow—that they can ever be solved in a way compatible with economic operation. I, therefore, maintain that the first question that should be answered is: *if* we are to have supersonic civil aviation.

The two problems I am referring to are those of *sonic booms* and *cosmic radiation.*

To indicate the severity of the sonic boom problem, it might be mentioned that a 180-ton Mach 2 or 3 airliner flying at 70,000 feet, presumably carrying some 100 passengers, would sweep the Earth's surface with a thunder-like noise along the entire supersonic flight path, rattling and often shattering windows, and awakening sleeping people within a band disturbance some 70 miles wide. Never before in history would so many have been disturbed so much by so few! Is it justifiable that millions of people in populous areas should lose sleep so that about a hundred passengers in an aircraft might gain a couple of hours in flight time from, say, New York to Los Angeles? Despite my enthusiasm for aviation, my answer to this question is "No!"

The example I have given, of the effects of a single supersonic flight, further illustrated by Figure 1, does not by a long way indicate the full severity of the problems confronting us. Let us be quite clear about two facts:

(*a*) Once supersonic aviation has been introduced, it will grow indefinitely—if it is at all an economically sound proposition.

(*b*) Once it is introduced, but ultimately found to be a mistake because of protests of the public, the airlines will not be able to turn back to pure subsonic civil aviation without economic disaster.

One just cannot wake up—perhaps aided by a few sharp sonic bangs in the middle of the night—to a delayed state of common sense and declare that all these huge, sleek and beautiful aircraft, immensely expensive masterpieces of science and engineering, were quite nice to have for a while, but have now become so disliked by the world's population that we had better scrap them all. So the point I wish to make is that we have arrived at one of the most important cross-roads in technological history, not merely for aviation people but for all Mankind. Personally, I think this is quite obvious. We just cannot—or at least should not—bombard larger and larger portions of the Earth's surface with sonic-boom thunder of ever-increasing frequency without giving, in advance, full consideration to all the implications.

It might be argued that all means of transportation (railways, trucks, airports) are noisy. That is right, but the very big difference is that whereas it is physically possible to move away from railways, highways and airports, hundreds of millions of people would never be able to move away from sonic booms, once we had the questionable blessing of supersonic aviation over the continents. Another significant difference is that sonic bangs are quite sharp, sudden and unexpected, whereas present airport noise is of a gradual character to which the neighbours can to some extent get accustomed.

The most important potential consequence of sonic bangs is that of widespread broken sleep—and sleep is of fundamental importance for health. It would, of course, be possible to impose restrictions on supersonic aviation—for instance, to daytime or oversea operation. Obviously that would considerably limit the supersonic market, with adverse effects on its profitability; and yet I doubt whether even with such restrictions supersonic aviation would be justifiable from sociological, medical and legal points of view. People should have a right to enjoy the maximum possible quietness even in daytime, especially those in hospital and in resort districts. It should even be remembered that quite a few people are dependent on undisturbed sleep in the daytime because they work at night. People should also be able to enjoy sea cruises for recreation without being awakened at night and frightened in the daytime. Furthermore, one should not forget the necessity for both passenger and cargo ship crews—often working in shifts—to be undisturbed in sleep to a reasonable extent.

Tremendous legal problems will apparently be involved. Who would pay the compensation for hardships inflicted by decreased sleeping time, and for losses on account of reduced working capacity? Can one neglect the possibility of, for instance, people with weak hearts being killed by sudden sharp sonic bangs?

Consideration must also be given to the sonic boom effect on animals. Many types of animals being bred at fur-farms are particularly sensitive to the rather low and gradual noise created by subsonic aircraft, and the sudden nature of sonic bangs might cause still greater losses than the fur-farmers have so far experienced. Besides such commercial interests, the various societies for prevention of cruelty to animals should be made aware of the implications so far as they may affect domestic animals.

It is my conviction that, primarily for medical and social reasons, supersonic aviation—be it in day or night time, over sea or over sparsely populated areas—should be permitted only if the operators can guarantee that the sonic booms will be below a specified limit—a limit set so low that light sleepers will normally not be awakened by sonic bangs of that magnitude. At the present state of the art, and in the foreseeable future, such a requirement cannot be satisfied economically, for it would limit size of supersonic aircraft to fighter-like dimensions (Figure 2).

Nor is the question of the acceptable intensity of sonic booms, in my opinion,

an issue that should be determined on the basis of the number of complaints. Such an attitude could result in concentrating supersonic civil aviation over sparsely populated areas or over sea, because "only" say, hundreds of thousands of people and not tens of millions would then be afflicted. I feel very strongly that it would be ruthless and against humanitarian principles to legalize harmful effects on people merely because they are relatively few in numbers. In particular, it should be observed that people might have chosen to live in—or might have moved to—a sparsely populated area just for the sake of enjoying quietness and solitude, or for health reasons.

In the public interest, and in the interest of the aircraft industry itself, there is an obvious step which should be taken at this stage, before enormous sums of money have been committed to the development of supersonic airliners. *Extensive test flights with existing military supersonic aircraft should be conducted in various countries so as to assess the relationship between sonic bangs and disturbance effects on population* Such test flights should be made at various altitudes so as to create a range of intensities, and the aircraft should be flown—with different frequencies—both by night and day over various typical districts such as cities, countryside areas and seas frequented by ships. The tests should be supervised and evaluated by medical experts. Although public reaction in the form of complaints and opinion polls should be assessed, the disturbance in particular as it affects sleep, should also be determined on a scientific medical basis

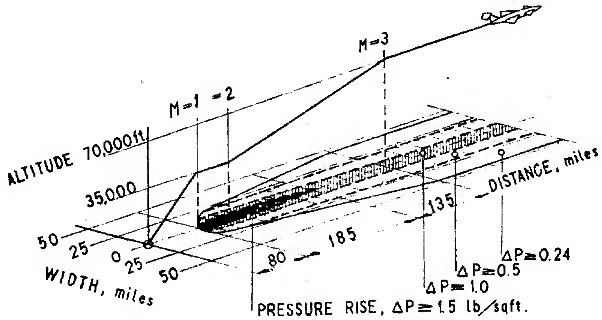

FIGURE 1. *The "sonic bang carpet" for an airliner of 300,000 lb all up weight accelerating through the transonic range (M=1) at 35,000 ft altitude and thereupon climbing at increasing supersonic speed to M=3 at a cruise altitude of 70,000 ft. Pressure rises from 0.3 to 0.5 lb/sq. ft will be experienced on the ground as distant explosions or thunder, from 0.5 to 1.0 as tolerable but often bothersome disturbances and from 1.0 to 3.0 as very close range thunder, causing some window damage (see below).*

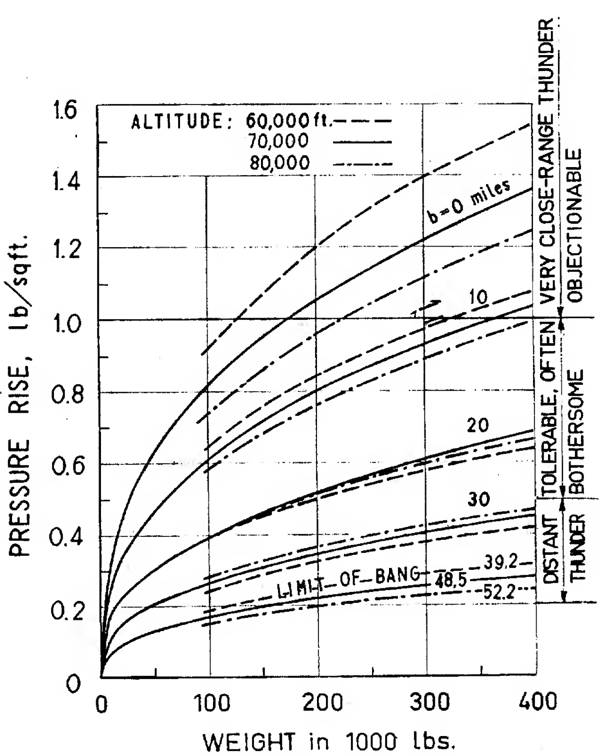

FIGURE 2. *Pressure rise and widths of the sonic bang carpet vs. aircraft weight for a Mach number of 3 and various cruise altitudes (b indicates lateral distance from flight path). The pressure rise is about the same for Mach numbers down to 1.3.*

The view has been expressed that if the *en route* sonic-boom noise disturbance would be no worse than the present "tolerable" airport noise, then it would —or must—be accepted by the public. My own conviction is that if supersonic aviation were to be launched upon us on the basis of such a complete misjudgment of what is at stake the result would be a public reaction so severe as to cause extensive prohibition of this new form of civil aviation.

Let us now turn to the other fundamental problem—cosmic radiation. It is well known that the so-called total ionization due to cosmic rays has its maximum around 70,000 feet—that is to say, at the very altitude at which the planned supersonic civil aircraft will fly. Here the intensity might be 200 to 300 times stronger than at the Earth's surface, and the primary cosmic rays (mostly very energetic protons) penetrate to this level (Figure 3, overleaf). During solar storms the radiation may intensify greatly, with an abundant production of neutrons where the rays encounter solid matter, such as an aircraft.

Not being an expert on the biological effects of radiation, I can only give some impressions received from statements by medical scientists on the subject. Some seem to maintain that there is *probably* no danger at all. Other experts are more dubious, stating (*a*) that one cannot neglect the possibility that the risk of developing cancer might increase for passengers who often fly at the heights in question; and (*b*) that the danger might be greater to future children of the passengers, due to genetic effects of radiation.

We should be quite certain, before entering upon the supersonic adventure, that harmful biological—in particular genetic—effects due to cosmic radiation at the "supersonic" altitudes are non-existent. It would not be sufficient if an increasing number of medical experts were to state that they *believe* the danger is probably negligible. It would be wrong to decide that only if such a danger were *proved* would we refrain from building supersonic civil

aircraft. What the prospective supersonic passenger has the right to demand is that it must be proven beyond doubt that the danger is non-existent. Thus the "burden of proof" with respect to the radiation hazard should fall on those who advocate supersonic aviation and on no one else And, of course, it must be borne in mind that it would take a considerable time before the genetic effects could be satisfactorily assessed, even if experimental animals were used to simulate the human being.

Life and Man have developed under the shield of the Earth's atmosphere, which gives protection from cosmic radiation. Why should we be so anxious to get above the major portion of this protection—up to heights where the density of the atmosphere is only about 6 per cent of the density at sea level—in less than a decade from now? Should we be much worse off if we waited a few more decades for supersonic airliners, so as to have time to acquire knowledge rather than beliefs about the hazards of cosmic radiation? This is an issue of first-rate importance.

No one wishes to obstruct progress in aviation, but I suggest that we take the time needed to reconsider what should be meant by progress in this field. Those of us who have been engaged in aeronautics for some decades have become accustomed to regard increases in speed as the chief measure of progress. That, in my opinion, is no longer correct. I believe that progress in aviation should be defined as implying the *greatest possible gain in time for the greatest possible number of passengers with the least possible disadvantage to people on the ground.* This concept puts emphasis on a large volume of aviation with low noise-level aircraft—as well as on short ground travel time to airports—rather than on extreme speeds.

Supersonic aviation, which must mainly be long-range, can only offer a limited market. In scheduled passenger transportation, subsonic aviation has already in many countries (for instance, the USA) practically absorbed the transport market on long distances, and is the dominating means of transport for medium-distance travel; the same development is under way in other countries. The percentage encroachment of aviation upon the commercial short-haul market (say, below 500 miles) is, however, rather meagre even in the USA, and if we consider the "short short-haul market" (say, below 100 miles), aviation is practically non-existent. Yet the number of passenger-miles travelled over short distances is much greater than for long distances. Thus, the biggest transport market, short-haul traffic, remains to be conquered, or at least to be appreciably encroached upon, by aviation. This applies also to private travelling and to freight transportation.

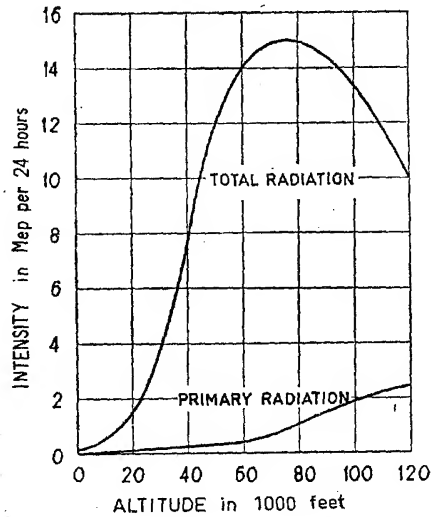

FIGURE 3. *Ionization intensity of cosmic radiation at various altitudes; from: Schaeffer, H. J.:* The Journal of Aviation Medicine, *23, 1952, p. 334, valid for about 50° latitude. The intensity is expressed in Mep, "milliroentgen equivalent physical", per 24 hours.*

As will be appreciated, great advances in short-haul aviation can materialize only by means of efficient V/STOL (Vertical and Short Take-Off and Landing) aircraft. Construction of economical V/STOL aircraft—which definitely is within the possibilities of the present state of the art—is, therefore, a much more urgent and profitable line of development than supersonic aircraft will ever be.

There are, of course, many other potential lines of development besides V/STOL aviation that are equally important, including: laminar boundary layer aircraft (implying power economy and so low passenger fares); ground effect machines, such as hovercraft; airport noise abatement; blind landing and take-off systems; building of large numbers of fairly small "V/STOL-airports" within or close to the city boundaries in order to save ground travel time; and last, but by no means least, increased safety in aviation—including the traffic control and anti-collision devices which will be required to make the intense future V/STOL traffic around our cities sufficiently safe.

Safety in aviation is of tremendous importance. With the optimism I have, in particular concerning the potentialities of V/STOL aviation, I believe that forty to fifty years from now commercial and general aviation—including private flying—all over the world could have a volume in passenger miles some 50 to 100 times the present world volume (excluding Russia and China). If the present fatality rate increased in proportion to the passenger miles flown we would then have about 100,000 passengers killed each year, implying at least five air accidents every day, which would be quite intolerable.

In my opinion, we have to set as a target that *the absolute number of accidents per year must not increase appreciably.* To comply with this requirement, we have to improve safety at the same rate as the growth of aviation, and this would imply an improvement by a factor of 50 to 100 by the end of the century. In view of the fact that no appreciable improvement in the fatality rate has been attained for many years in spite of all efforts, a raising of the safety level even by a factor of 5 to 10 is indeed a formidable task.

Such improvements can certainly not be attained without some radically new approaches to the aviation safety problem, comprising all facets of the business from the conception, design and manufacture of new aircraft to operation of the fleets, with employment of, *inter alia*, the most advanced electronic devices compatible with the state of the art at any time.

If the Western world were to postpone the supersonic adventure two decades—or longer, if necessary—to assess and overcome the sonic boom and cosmic radiation hazards, and the vast sums of money thus saved were instead spent in all the other avenues of aeronautical research and development which I have indicated, with safety, V/STOL and low-fare subsonic jet transports at the top of the priority list, we should achieve a much greater and more soundly based expansion of civil aviation than by concentrating on the limited supersonic market.

Finally, what about the *prestige* aspect? It has been stated that the free world must fly supersonic before the Russians do it. I doubt it.

I believe that we should judge for ourselves what limitations on intensity of sonic bangs and radiation (or altitude) must be enforced to protect people on the ground and in the air. So long as we cannot avoid the disturbing supersonic boom noise with economically large aircraft or assure the non-existence of radiation hazards at "supersonic" altitudes, I think we should refrain from supersonic aviation. I take for granted that we can prohibit others from flying supersonic above—and creating sonic bangs within—our countries and territorial waters.

If we have to think in terms of a race with Russia, let us engage in a "race of common sense" instead of a "supersonic race"; let us compete to ensure the highest level of safety and low-fare high-speed subsonic aviation, implying commercially sound and profitable mass air-transport of people and freight. This is indeed one of the most efficient means conceivable for increasing the standard of living of the Western countries and for welding them together culturally and economically.

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It has been found that if mice are kept in a cage under such a lead plate and simultaneously exposed to the influence of cancer-developing substances, cancer is more rapidly developed - and developed in more animals - than is the case with mice which are not covered by such a plate. Under the same conditions the embryos of pregnant rabbits have been found to suffer injuries, as the embryos are particularly sensitive to ionizing radiation. An influence of the amplified radiation on plants and bacteria has also been observed. Finally, it has been shown that, with amplified cosmic radiation, mutations appear in an increased number in research animals. By conducting the cascade experiment in Alpine districts where radiation is obviously stronger, more apparent biological effects are obtainable.

Not long ago two American scientists who have worked with such cascade experiments independently pointed out the possibility that people in industrial cities could be thought to be more exposed to the influence of cosmic radiation due to a cascade effect from steel structures and so on, and that they could therefore develop cancer more easily than people living in the country. However, these viewpoints do not yet seem to have been investigated systematically to give any conclusive results.

Civil aircraft personnel, who must obviously spend long periods at relatively high flying altitudes, are subject to an increased exposure to cosmic radiation, which is approximately 40 times stronger at a height of 9,000 metres (30,000 ft) than at ground level. In an aircraft, however, the altitude is not the only unfavourable factor as a certain cascade effect developed by the aircraft fuselage is also present. Aircraft personnel must therefore be subject to a somewhat greater risk of injury to the sex-cells, resulting in congenital development irregularities of descendants, than people on average; it is also conceivable that cancer risk is somewhat increased.

If the flight altitudes of the future should be increased to 20,000 - 25,000 metres (65,000 - 85,000 ft), this will imply not only an increased long term risk for the personnel, but female passengers in the first months of pregnancy will probably run an acute danger of fetus injuries, resulting in abortion or deformities.

The possibility of shielding crews of jet military aircraft, which are already operating at extremely high altitudes, has been seriously discussed, but consideration of this has had to be abandoned. Materials which contain considerable amounts of hydrogen atoms, e.g. water and certain liquid fuels,

should, it is true, lend themselves as shields, but such thicknesses are required that the practical realization appears to be impossible. It has been necessary to be satisfied with a recommendation that over-long flight durations at these heights should be avoided.

During the past 7-3 years, the interest has to a great extent shifted to the conditions at still greater altitudes. The total ionization decreases above 23,000 metres (76,000 ft), but at the same time, the character of the radiation changes. Here one encounters the so-called primary cosmic radiation, which consists of heavy atomic nuclei with enormously high ionizating effects, equivalent to thousands of Roentgen (r) units, and which decreases towards the earth's surface, where it is very insignificant.

The influence of primary radiation has been experimentally studied with research animals by exposing them at ground level to other forms of ionizing radiation having a somewhat comparable effect, but, above all, during recent years it has been possible with help of balloons to lift research material to altitudes of over 30,000 metres (98,000 ft), where primary radiation is strong. Principally, however, the so-called ichnography or "sandwich method" developed by a Swiss scientist has come into use. This method permits a study of the influence of radiation on single animal cells. A perforated plastic plate like a honeycomb has a living ovum of a suitable animal type (Artemia salina) placed in each cell. On each side of it a photographic plate, of the type used for studying cosmic radiation, is located. With microscopic investigations after radiation exposure, one can see on these plates where the high-energy cosmic particles have passed, and in this way information can be obtained on what cells have been struck. It has been found that the ovum struck have been killed, and do not develop into embryos, while the development of the remainder proceeded normally.

In recent years American scientists using balloons have sent up mice and guinea-pigs in sealed metal containers to a height of 38,000 metres (125,000 ft) where they stayed for 24 hours. Most of the animals died during the experiments because of cold and lack of oxygen, but, on the survivors, numerous patches of white hair were observed indicating injuries to the roots.

It has been calculated that if a human being found himself in these regions, his body would be struck by 100 atomic nuclei per hour, and the number of cells destroyed would be about 15,000. The biological significance of this influence cannot be stated with certainty. It has been said that the

immediate injuries would be comparable with those that would arise if a large number of extremely small sterile needles were stuck through the body. At a distance from the earth, e.g. in the present satellite orbits, at least twice the dose of cosmic radiation can be expected, as the earth's screening effect disappears. Even there, the damage to cells can be quantitatively fairly small, say about 3 million cells per hour, an unimpressive figure when one considers that during the same period 3-10 billion red blood cells are normally destroyed and replaced in a human being. One should hardly need to consider that any acute injuries would appear, but when judging long-term effects, one must remember that cells which cannot be replaced by regeneration would also be destroyed to a certain extent: the brain and spinal cord nerve cells and the most important part of the eye, the retina. The risk should also be taken into account that, after a longer or even a shorter stay in space, the lens of the eye may be clouded, in other words that cataract may develop.

Finally, at least for extended periods in these regions, there is reason to fear a probable risk of severe injuries to the sex-cells giving rise to hereditary deformities and diseases and rendering descendants unfitted for a normal life. One can also assume that the metal structure of an interplanetary space vehicle will increase the radiation effect, and it seems at present that there is no way of providing a shield.

Quite simply, it appears that mankind must accept the fact that a certain price must be paid in the form of body injuries for the pleasure of leaving this globe and its shielding atmosphere, if moon trips are to begin sometime in the future.